SKID RESISTANCE OF WOOD FLOOR FINISHES

UNDER VARYING SURFACE CONDITIONS

by

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The objectives of this study were to determine the coefficients of friction of various combinations of wood floor finishes and heel materials; to determine the effect of wood floor waxes on the frictional values of wood floor finish and heel material combinations; and to compare the coefficients of friction of new, worn, and waxed wood floor finishes in combination with heel materials.

Seven wood floor finishes - penetrating seal, satin and gloss varnish, lacquer, shellac, polyurethane, and epoxy - were applied to red and white strip oak flooring placed in both lengthwise and crosswise grain directions. The wood floor finishes were waxed with a liquid and a paste solvent base wax, a paste skid resistant wax, and a self polishing wax. The finishes were tested in combination with leather, rubber, nylon, Neolite and rubber crepe heel materials. All Combinations of materials were tested dry and with moisture applied.

The Bowen Friction Tester was used to obtain force of friction values. Coefficient of friction values were computed and used in this study as the measure of skid resistance.

The data were treated to an analysis of variance. Two separate experiments were analysed corresponding to the wet and dry conditions of the tested materials.

Results revealed significant differences in skid resistance among wood floor finishes, heel materials and surface conditions, both dry and with moisture applied; between oak types when dry; and between grain directions with moisture applied.

The coefficients of friction were generally higher for materials in the dry experiment than with moisture applied.

In the dry experiment, the epoxy finish gave the highest, and the penetrating seal the lowest, coefficient of friction. However, the wood floor finishes ranked differently with moisture applied than when dry. With moisture applied epoxy ranked lowest, and lacquer highest of the seven finishes.

In both experiments the leather heel material gave the lowest, and the rubber crepe heel material the highest coefficient of friction. Nylon, rubber, and Neolite gave similar coefficients of friction and ranked about halfway between the leather and rubber crepe heel materials. Much greater variation was noted in the coefficients of friction of heel materials than in the coefficients of friction of finishes or surface conditions.

In general, waxing lowered the coefficients of friction below what they were in the unwaxed conditions. The self polishing wax consistently gave higher coefficients of friction than the other waxes. The solvent base waxes ranked lowest in both experiments.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FIGURE PAGE

CHAPTER I

INTRODUCTION

Skid resistance is one of the qualities frequently mentioned as an important consideration in the selection of flooring materials. Literature available to the consumer emphasizes ease of maintenance and appearance but provides little or no information on the relative skid resistance of various flooring materials. Some skid resistance testing has been completed on resilient and hard floor surfaces but little, if any, has been done on wood floor finishes which are used extensively in homes.

Information on skid resistance is needed as one means of preventing accidents due to slips and falls. Each year accidents account for a high percentage of the injuries and fatalities in the United States. Falls as a cause of accidents rank second only to transport deaths.[1] The majority of deaths from falls occur in persons age 44 or older, the rate steadily increasing with age. However, non-fatal injuries in all age groups that require medical care or curtailed activity are still a leading type of accident.[2]

Four major factors are usually cited as being responsible for slips and falls on flooring surfaces: (1) the material and condition of

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[1]"Accidental Death and Injury Statistics," (United States Department of Health, Education and Welfare, Public Health Service, Division of Accident Prevention, Washington, D. C., 1963), p. 8.

[2]*Ibid.*, p. 8.

the floor surface; (2) the material and condition of the shoe coming in contact with the flooring surface; (3) the physical condition of the walker, including handicaps, nature of step or stride, agility and age; and (4) the mental condition of the individual doing the walking; for example, his psychological reaction to any shine on the floor. Of these four factors, the first, the material and condition of the floor surface, is the only one that can be appreciably affected by the actions of the owner of the floor.[3]

Information on the relative slip resistance of flooring materials needs to be available to those responsible for selecting safe flooring surfaces for the home. This information should also be available to anyone with the responsibility for maintaining the surface after its installation to be sure the original slip resistant qualities are preserved and possibly improved.

I. THE PROBLEM

This experiment, the "Skid Resistance of Wood Floor Finishes under Varying Surface Conditions," is a phase of a larger project entitled, "The Testing of Smooth Floor Surfaces and Finishes from the Standpoint of Safety," which contributes to Southern Regional Housing Research Project S-54.[4] As part of this project, hard and resilient floor surfaces have been tested for skid resistance.

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[3] "Floor Safety is No Accident," Institutions Magazine, June, 1958, p. 56.

[4] "Environmental and Economic Factors Related to Improved Rural Family Housing in the South," (Southern Housing Project S-54). (Mimeographed.)

The purposes of the current study are: (1) to determine the coefficient of friction of various combinations of wood floor finishes and heel materials: a) in a dry condition, and b) with applied moisture; (2) to determine the effect of wood floor polishes on the frictional values of wood floor finishes and heel material combinations: a) in a dry condition, and b) with applied moisture; (3) to compare the coefficients of friction of new, worn and polished wood floor finishes tested in combination with heel materials: a) in a dry condition, and b) with applied moisture.

II. DEFINITIONS OF TERMS USED

Force of Friction (kinetic): the resisting force which opposes any effort to roll or slide one body over or through another. It is directly proportional to the normal force.

Wood Floor Finish: a coating or sealer applied to bare or raw wood surfaces for the purpose of protecting and preserving the natural appearance of the wood. In this study, the term finish is not synonymous to the term wax or polish.

Floor Wax: a temporary coating applied to floor surfaces for the purpose of protecting and enhancing the floor surface or the floor finish.

CHAPTER II

THE REVIEW OF THE LITERATURE

Since 1926 a number of methods have been developed for the measurement of skid resistance of floor surfaces. Most of the testing, however, has been on hard and resilient floor coverings. That completed on wood flooring is very limited. A few studies tested wood among their materials, but none have tested or compared wood floor finishes. Following is a review of studies of skid resistance of floor surfaces and an evaluation of test methods.

I. MEASUREMENT OF SKID RESISTANCE OF FLOOR SURFACES

American Standards Association Project

The American Standards Association Project A-22 was set up to formulate a safety code for walkway surfaces. Finding the available data on walkway surfaces to be inadequate for this purpose, the Project A-22 Committee made arrangements for the National Bureau of Standards to conduct an experimental investigation of the frictional resistances of walkway surface materials. Data from this study were to be used in the formulation of a safety code.[1]

A report of the investigation was made in 1926. The incompleteness of the research prompted an additional investigation in 1928-29.

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[1] R. B. Hunter, "A Method of Measuring Frictional Coefficients of Walkway Materials," National Bureau of Standards Journal of Research, V (August, 1930), 330.

The latter study tested 24 specimen that included: a) smooth faced natural stone products such as slate, marble and travertine; b) wood including maple, larch and yellow pine flooring; c) artificial stone products; d) manufactured products - compressible smooth faced resilient floor coverings such as rubber, linoleum and cork; e) clear metal surfaces; and f) ridged or roughened metal products.[2]

Coefficient of friction values were obtained for: a) clean, dry, leather soles and clean, dry, worn walkway materials; b) clean, wet, leather soles and clean, wet, worn walkway materials; c) dirty, wet, worn specimen of walkway materials and dirty, wet, leather and rubber soles; d) oily worn specimen of walkway materials and oily leather and rubber soles.[3]

The Hunter Friction Tester used for this study "operates on an oblique thrust principle corresponding to the thrust on the shoe in walking."[4] A 75-pound weight is supported in a raised position between two vertical bars of the frame by the friction between the shoe and the surface being tested. As the shoe is drawn forward by a screw and lug, the horizontal component of the force is increased. When the shoe slips, the weight drops, leaving the lug in the position where the slip occurred. The coefficient of friction can be read from a scale attached to the lug.[5]

Results indicated that there would be little direct relation between the clean dry surfaces tested in the laboratory and the same surfaces tested in actual service conditions.[6] The measurements were therefore limited for use in a safety code for walkway surfaces until the measures could be correlated with walkways in actual service.[7]

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[2]*Ibid.*, p. 331. [3]*Ibid.* [4]*Ibid.*, p. 323. [5]*Ibid.* [6]*Ibid.*, p. 333.
[7]*Ibid.*, p. 346.

Slipperiness of Untreated and Treated Felt Base Floor Coverings

The purpose of a 1941 study at the New York State College of Home Economics was to determine whether felt base floor coverings were more skid resistant in a polished or unpolished condition.[8]

Coefficient of friction values between shoe materials and floor covering materials were obtained by two methods. The first was a force weight determination. A sample piece of flooring material was placed on a horizontal surface. A sample of shoe material rested on this flooring material. A cord attached to the shoe was led over a pulley and attached to a container hanging perpendicularly to the floor surface. Sand was poured into the container until the weight caused the shoe to move across the surface.[9]

In the second method, a simulated shoe was placed on the end of an inclined plane covered with the flooring material to be tested. The end was raised until the shoe started to slide down the surface.[10]

Preliminary tests on floor coverings showed that variations in measures were less when the force weight method was used. This method was used in subsequent testing on 34 samples of felt base floor covering samples in new, worn and polished conditions.[11] Six polishes were used including water emulsion, liquid solvent, and paste wax.[12]

[8] Mary Louise Thompson, "Measurement of the Relative Slipperiness of Untreated Felt Base Floor Covering and of that Treated with Wax Finishes" (unpublished problem for Master of Science degree, The New York State College of Home Economics, Cornell University, Ithaca, N. Y., 1941), p. 2.

[9] Ibid., p. 4. [10] Ibid. [11] Ibid., p. 7. [12] Ibid., p. 9.

Results showed that for both new and worn samples the waxed surfaces were less slippery than the unwaxed surfaces,[13] and that the worn felt base floor coverings were generally less slippery than the new floor coverings.[14]

1947 Joint Research Project of the National Safety Council and the National Bureau of Standards

In an attempt to reduce the frequency of accidents due to falls on walkway surfaces, the National Safety Council and the National Bureau of Standards undertook a joint research project to obtain data for the formulation of a walkway surface safety code.[15]

The research was conducted in several phases. The first phase was a study of the mechanics of walking for the purpose of developing an adequate method of measuring slipperiness. Slow motion pictures of people walking were made with concealed cameras. These pictures revealed that the rear edge of the heel is the first part of the foot to come in contact with the walkway surface. A follow-up survey showed that the maximum wear usually occurred at the outside border of the rear of the heel and that the average angle of contact was 19° for women's heels, 23° for men's heels, and 26° for worn heels.[16]

Following this phase a portable slipperiness tester of the pendulum impact type was designed and constructed for use in actual service conditions. The design of the tester was based on the premise that, in

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[13] Ibid., p. 8. [14] Ibid., p. 10.

[15] Percy S. Sigler, Martin N. Geib, and Thomas H. Boone, "Measurement of the Slipperiness of Walkway Surfaces," Journal of Research of the National Bureau of Standards, Research Paper RP1879, XL (May, 1948), 339.

[16] Ibid., p. 340.

the process of ordinary walking, slipping is most likely to occur when the rear edge of the heel contacts the walkway surface. For testing one and one-half inch square test pieces of heel material were attached at various angles to the end of a pendulum. The heel material was impacted onto and swept over the walkway surface being tested. A scale attached to the framework measured the energy used in sliding the heel over the walkway surface or the frictional force times the distance of contact.[17]

Several investigations were made to determine the effect of varying the constants of the instruments. The angle of contact between the heel and walkway surface was varied using angles of 10°, 20°, and 30°. A slight decrease in friction values was found with an increase in the angle of contact. Since the differences were too small to be considered significant, an angle of 20° was adopted for general use. The effect of varying the pressure between the heel and walkway surface was also studied. Forces of 3.7, 6.7, and 11.2 pounds were used. In general, lower friction values were obtained with an increase in pressure.[18]

The second phase of the research was a laboratory study in which rubber and leather heels were tested under both wet and dry conditions. Twenty-three tests were made on a variety of walkway surfaces of the resilient, hard and wood floor types. Results showed the coefficients of friction to be relatively high when the walkway surfaces were tested with dry rubber heels. In a wet condition friction values were low enough to be considered hazardous with both rubber and leather heels.[19]

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[17]*Ibid.*, pp. 340-341. [18]*Ibid.*, p. 342. [19]*Ibid.*, p. 343.

After the laboratory study was completed, an extensive field study was made of untreated and treated asphalt tile corridors in a government building in Washington, D. C. Leather and rubber heels were used in both wet and dry conditions. Measures were repeated at various intervals to determine changes occurring in the slipperiness of the waxed floors after being exposed to normal maintenance and traffic.[20]

The waxed asphalt tiles had higher friction values than the untreated tiles when tested with rubber heels under dry conditions. The opposite was generally true for tests with the leather heel. When the corridors were wet, they were considered hazardous for both rubber and leather heels, and especially hazardous when wet and waxed. With dry maintenance and normal traffic, the friction values of the waxed asphalt tiles improved.[21]

Based on the results of these tests, the following conclusion was drawn: "that a slippery condition does or does not exist according to whether the measured coefficient is less or greater than 0.4."[22]

ASTM Proposed Methods for Measuring the Coefficient of Friction of Waxed Floor Surfaces

In 1954 the D-21 Committee on Wax Polishes and Related Materials of the American Society for Testing Materials reported on two proposed methods for evaluating the antislip properties of smooth surface floors polished with emulsion type floor waxes.[23]

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[20] Ibid., p. 345. [21] Ibid., p. 346. [22] Ibid.

[23] "Proposed Method of Test for Measuring the Static Coefficient of Friction of Waxed Floor Surfaces," American Society of Testing Materials Bulletin, No. 196 (February, 1954), p. 20.

The first was a method of testing static coefficient of friction of floor surfaces, using a testing apparatus developed by S. V. James of the Underwriters' Laboratories, Inc. The James Machine was designed to simulate conditions under the sole of the foot during the middle and latter portions of a stride. It is not suitable for testing wet, rough, or corrugated surfaces.[24]

Testing was done with a shoe sole of leather sanded to a smooth flat surface on six inch square panels of Tentative Official Test Linoleum prepared with wax. Coefficient of friction values were obtained.[25]

In 1958, after several years of experience with the James Machine, the D-21 Committee stated that complete correlation between the machine and actual service foot tests could not be expected since the materials in service would differ in roughness, cleanness, dryness, and polished condition. They further stated that the coefficient of friction must always be measured as a result of three different materials--the shoe used, the wax and the substrate, and that no correlation between laboratory tests and service tests could be expected unless the three materials were identical.[26]

James in discussing the attributes of various machines used for testing skid resistance, his own included, observed that a floor finish would be considered safe if after the application of the finish the co-

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[24]Ibid., pp. 31-32. [25]Ibid., p. 20.

[26]"Evaluating the Slip Resistance of Floor Waxes, the Significance of Friction Measurements," American Society for Testing Materials Bulletin No. 232 (September, 1958), p. 32-33.

efficient of friction is as great or greater than the untreated floor surface, assuming, of course, that the untreated floor surfaces were safe.[27]

The second proposed method of the D-21 Committee was for testing the kinetic coefficient of friction of floor surfaces. The testing apparatus used was the one developed by the National Bureau of Standards and used in its 1947 study. It was known as the Sigler Pendulum Impact Type Slipperiness Tester. The purpose of the tester was to evaluate small test panels in laboratory conditions, but it could also be used to measure slip resistance of floors in actual service. The Sigler machine was used to test leather heels in combination with linoleum.[28]

The 1958 review of the D-21 Committee emphasized that this method was of a low order of precision as were the tests with the James Machine. The machine friction values could not be expected to correlate in all cases with foot tests on the floor or with safety in use, since slips and falls are frequently caused by factors not determinable by a laboratory machine, such as loose litter and water.[29]

The Dura Slip Resistant Tester

The Dura Slip Resistant Tester was designed to operate on the same principle as the James Machine; is portable, and automatic and thus

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[27] Sydney V. James, "What is a Safe Floor Finish," Soap and Sanitary Chemical, XX (October, 1944), 115.

[28] "Proposed Method of Test for Measuring the Dynamic Coefficient of Friction of Waxed Floor Surfaces," American Society for Testing Materials Bulletin, No. 196 (February, 1954), p. 21.

[29] "Evaluating the Slip Resistance of Floor Waxes," op. cit., pp.34-35.

can test floors in actual service as well as in the laboratory. The tester measures static coefficient of friction.[30]

A shoe sole material is attached to a slanting metal bar hinged to a vertical column carrying a thousand gram weight. The shoe material rests on the test surface which is driven away from the weighted column until the sole material slips forward on the test surface. The coefficient of friction is read from a graduated scale.[31]

The test sole material was of leather and was tested in combination with linoleum, asphalt tile, rubber tile, and vinyl tile. The flooring materials were tested in an untreated condition and in a treated condition. Two polishes were used on the floor coverings, one a typical household type and the other a typical maintanance floor wax.[32]

Data were obtained using both the Dura Slip Resistant tester and the James Machine. The results compared favorably on both treated and untreated surfaces, and indicated that rubber had the highest coefficient of friction of the floor surfaces. It was followed by linoleum and asphalt tile, with vinyl tile having the lowest coefficient of friction.[33]

Simple Slip Test for Wax

Tests of skid resistance reported by the Hospital Bureau Research News state that a slippery floor exists when the coefficient of friction is .3 or under and that a safe floor exists when the coefficient of

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[30]Bernard Berkeley and James D. Burns, "Floor Wax Slip Testing: Statistical Analysis of Dura vs James Coefficient of Friction Measurements," Soap and Chemical Specialties, XXXIII (April, 1957), 1.

[31]Ibid. [32]Ibid., p. 4. [33]Ibid., p. 5.

friction is .5 or more.[34] This coefficient of friction compares favorably with the report of the National Safety Council and the National Bureau of Standards in 1947.

The method suggested was to place ten pounds of lead shot in a canvas bag which was laid on top of a layer of cheese cloth attached to a spring scale. With the scale, the bag was then pulled across the floor.[35]

Research on Stairway Safety 1957-1961

A field study of home stairway accidents conducted at Michigan State University in 1957 showed that slipping was the cause of most falls and that tread covering materials were responsible for many of these.[36]

Consequently, a method was established for determining coefficients of friction of stairway tread covering materials in combination with shoe sole materials.[37]

The machine used to collect data consisted of a movable table to which the tread material was fastened. The table was then pulled under the shoe sole which was fastened to a holder. The force required to move the table under the sole was recorded on an oscillograph.[38]

Preliminary tests were run with various combinations of common tread and shoe sole materials. The tread materials included linoleum, rugs, wood, abrasive materials, and rubber mats. Neoprene, crepe, leather,

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[34] Hospital Bureau Inc., " Simple Slip Test for Wax," Bureau Research News, V (December, 1958), 3.

[35] Ibid.

[36] Agricultural Engineering Department of Michigan State University and North Central Farm Housing Committee, "The Cause and Nature of Stairway Falls," (Michigan Contributing Report for 1959), p. 1. (Mimeo.)

[37] Ibid. [38] Ibid.

and travelite were the sole materials used. Results showed a decrease in the coefficient of friction with repeated testing of new materials. Neoprene and crepe had the highest coefficients of friction for sole materials, while leather had the lowest. Of the tread materials the coefficients of friction were relatively high with scotch tread, abrasive, wood, and linoleum. Lowest values were obtained with rubber mat, waxed sealer, wool rug, and marble.[39]

In a following study using the same machine, six types of tread covering materials were tested in combination with six shoe sole materials.[40] The tread and sole materials were tested both new and worn. In the new condition results showed that the abrasive strip had the highest coefficient of friction of .75. Varnish, rubber mat, paint, and wood had values near .63, while linoleum had the lowest coefficient of friction of .56. This was a reversal of the results of the preliminary study. In the worn condition, values increased slightly for linoleum and rubber mat and decreased for wood and paint.[41] The ripple sole had a considerably higher friction value than any of the other sole materials tested, while leather had a coefficient of friction much less than one-half that of the ripple sole. Other materials tested were Neoprene, Neolite, crepe, and rubber. All but crepe showed an increase in coefficient of friction with use.[42]

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[39] Ibid., p. 2.

[40] Merle L. Esmay, "Home Stairway Safety Research Results," (East Lansing: Agricultural Engineering Department of Michigan State University, 1961), p. 5. (Mimeographed.)

[41] Ibid., p. 8. [42] Ibid., p. 10.

Skid Resistance of Smooth Floor Surfaces 1961-1965

Researchers at the University of North Carolina at Greensboro have tested the skid resistance of resilient and hard floor surfaces in combination with various shoe heel materials. Coefficient of friction values were obtained with the use of the Bowen Friction Tester which is described in Chapter III.

Nine resilient floor materials were tested in combination with five heel materials in new, worn, and polished conditions, both wet and dry. Results showed that linoleum had the lowest coefficient of friction values, followed by plain cork. Rubber and solid vinyl gave the greatest skid resistance. Of the heel materials, leather was the most slippery, while rubber crepe was the least. The skid resistant polishes tended to increase the friction values on most of the dry floor materials, while the opposite was true when the floor materials were tested in a wet condition. The clear and ordinary polishes generally decreased friction values of both wet and dry floor surfaces. No one polish was found to be superior in its effect on the coefficient of friction of floor materials under all conditions tested.[43]

The resilient floor materials tested in a dry condition with urethane rubber, hard rubber, neoprene cord, and crepe heels showed relatively high resistance to slipping. The friction values were considerably lower when these materials were tested in a wet condition.

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[43] Savannah S. Day and Elizabeth Shamburger, "Factors Affecting Skid Resistance of Resilient Floor Coverings," Reprinted from Hospitals, Journal of the American Hospital Association, XXXIX (April 16, 1965), pp. 2-4.

But when the floor materials were tested wet with leather, the coefficients were higher than when the materials were tested dry with leather.[44]

Seven hard floor surfaces in polished and unpolished conditions, both wet and dry, were tested in combination with five heel materials. When tested dry, terrazzo was the least skid resistant and aggregate the most skid resistant. When tested wet, glazed ceramic was the least and quarry tile the most skid resistant.[45] Generally the polishes lowered the skid resistance of the hard floor surface materials as did moisture.[46]

Coefficient of Friction Machine 1965

The American Journal of Physics recently reported on the construction of a coefficient of friction machine developed by Daniel Nakshol of Tel-Aviv University, Israel.

The machine was designed to overcome problems inherent in the conventional method of measuring friction of pulling a body over a plane by means of weights exerting a constant force.[47]

The machine measures static coefficient of friction and consists of a disk which rotates under a stationary body with the use of a variable speed motor. The test body lies on the table and is connected by a connecting rod to a spring dynamometer which measures the force required to keep the test body stationary while the table rotates under it.

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[44] Ibid., p. 4.

[45] Marianne Hodges, "Skid Resistance of Hard Floor Surface Materials," (unpublished Master's thesis, The University of North Carolina, at Greensboro, 1965), p. 75.

[46] Ibid., p. 78.

[47] Daniel Nahshol, "Coefficient of Friction Machine," American Journal of Physics, XXXIII (February, 1965), 161.

One test material can be placed on each side of the table, and one on each side of the test body. Therefore, with one table and one test body, four different combinations of material can be tested.[48]

No information could be found on the type or results of materials tested with this machine.

II. REVIEW OF STUDIES TESTING WOOD FLOORING MATERIALS

Several investigations have been carried out on the slip resistance of flooring and walkway surfaces from 1926 to the present. The studies have concerned themselves mostly with hard and resilient floor surfaces.

Only three investigations provided data on wood floors and these were limited. The 1926 project of the American Standards Association tested three wood flooring specimen out of twenty-four. These included smooth maple, larch, and yellow pine flooring. Only the coefficients of friction of the maple flooring were reported and these ranged from .255 on oily surfaces with leather heels to .770 when clean and wet with a leather heel.[49]

The 1947 Joint Project of the National Safety Council and the National Bureau of Standards tested yellow pine sealed with a penetrating seal and waxed white oak. Both were tested in areas of actual service with leather and rubber heels. The coefficient of friction for the yellow pine floor tested in a dry condition with a rubber heel was .52; for the white oak, .49. Friction values dropped considerably (below .2) when both flooring materials were tested with rubber heels in a wet condition and with leather heels in both wet and dry conditions.[50]

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[48] Ibid., p. 162. [49] R. B. Hunter, op. cit., p. 343.

[50] Sigler, op. cit., p. 345.

Of twenty-three flooring materials tested, only two materials had coefficients of friction lower than the wood materials. The friction values of the wood materials tested in this study were lower than those of linoleum in most cases.[51]

The Michigan State study of stair tread materials included wood as one of the tread materials. Of seven materials tested wood ranked next to lowest with a coefficient of friction of .61, higher only than linoleum, which was substantially lower. This differs from the results of the study mentioned above. The friction value of the wood decreased with wear.[52]

While wood has been included in the above three studies, the data collected have been limited; and none of the studies have compared various wood floor finishes.

III. EVALUATION OF METHODS AND MACHINES FOR MEASURING SKID RESISTANCE

In 1961 a task group of technical personnel from six Federal agencies appointed by the Federal Construction Council reviewed methods in use for determining the relative slip resistant qualities of various surface materials.

The Task Group recognized the need for an acceptable standardized means of expressing and communicating degrees of slip resistance and for a method of measurement that could be used by persons responsible for the selection and maintenance of floor surfaces. The Task Group hoped

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[51] Ibid.

[52] Esmay, op. cit., p. 8.

to be able to recommend performance tests to be used as a basis for establishing slip resistant characteristics of various surfaces.[53]

The machines and methods reviewed by the Task Group included most of those mentioned in this review of literature as well as a number of others, including slip resistance measurement by practical evaluation with the foot used by large purchasers of floor waxes such as the General Services Administration and the American Telephone and Telegraph Company.[54]

This analysis of machines and methods of measuring slip resistance disclosed a number of factors which could affect the meaning and accuracy of data received from such tests: 1) different types of machines measure different types of friction; 2) no single method of measurement covers adequately the causes for all types of slips; 3) the elastic properties of floor materials; 4) different degrees of surface roughness for the same material; and 5) problems in controlling the boundary conditions between two surfaces.[55]

The Task Group concluded that "the data on friction, compiled from tests on the machines reviewed by the Task Group, are too closely associated with the type of apparatus used and the operator's techniques to be given broad significance."[56] The group felt that various materials tested on one machine under identical conditions could be compared with one another, but that materials tested with one machine could not be compared with materials tested on another machine.[57]

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[53]Building Research Advisory Council, Causes and Measurement of Walkway Slipperiness: Present Status and Future Needs, Federal Construction Council Tech. Report No. 43 (Washington: National Academy of Sciences, National Research Council, Publication 899, 1961), p. 1.

[54]Ibid., p. 19. [55]Ibid., p. 21. [56]Ibid., p. 2. [57]Ibid., p. 22.

In its recommendations for the future, the Task Group suggested the need for the development of a surface of controllable and reproducible roughness as a means of expressing slipperiness in terms of constant standards. They also suggested the development of a portable device to be used in the field to measure the slip resistance of flooring materials in a way that would relate the friction values to the standards. The standards and machine should be available for designers, manufacturers, and maintenance personnel for use in actual service conditions.[58]

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[58] Ibid., pp. 3-4.

CHAPTER III

EXPERIMENTAL PROCEDURE

The experimental procedures discussed in this chapter include the description of the testing apparatus, the selection of test materials, the testing procedure, and the method of data analysis.

I. DESCRIPTION OF THE TESTING APPARATUS

The friction testing machine used for this study was the Bowen Friction Tester.[1] The machine consists of three major parts: (1) a movable circular table, seven feet in diameter, which rotates under a weight platform-heel holder at a constant speed of fifteen feet per minute; (2) an electric motor; and (3) a mechanical recorder. A detailed description of the Bowen Friction Tester and procedures for using it are presented by Day et al.[2]

Floor samples are mounted on a 3/8-inch thick plywood ring which is attached to the circular table. A shoe heel material is attached to a platform on which weights are placed. As the table rotates under the heel material, the mechanical recorder charts the force of friction on a continuous graph.

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[1] Designed and constructed by Dr. Henry Bowen of the Department of Agricultural Engineering at North Carolina State University at Raleigh.

[2] Savannah S. Day, Fern Tuten, Jean Trogdon and Henry Bowen, "Measurement of the Skid Resistance of Resilient Smooth Floor Surfaces, Journal of Home Economics, LVI (December, 1964), 752-753.

The Bowen Friction Tester tests several floor coverings without interruption, differing from previous machines that tested one floor material at a time.

II. SELECTION AND PREPARATION OF TEST MATERIALS

Selection of Wood Flooring and Construction of Test Panels

Specifications of the Forest Service of the United States Department of Agriculture and the National Oak Flooring Manufacturers Association were used as guides in selecting the wood floor materials to be tested in this experiment.

Hardwoods are more widely used than soft woods for flooring material because of their resistance to wear and the beauty of their natural grain.[3] Oak, because of its strength and availability, is the hardwood most frequently used for flooring in homes.[4] The Forest Service of the United States Department of Agriculture reports that approximately 80 per cent of all flooring produced is hardwood and of this 92 per cent is oak.[5] Both red and white oak are processed into flooring, and literature indicates little difference in their quality or the quantity used. Both red and white oak are light in color, the red oak having a pink cast, while the white oak has a brownish tint.[6]

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[3]Forest Products Laboratory, Wood Floors for Dwellings, United States Department of Agriculture, Forest Service, Agriculture Handbook No. 204 (Washington: Government Printing Office, 1961), p. 3.

[4]National Oak Flooring Manufacturers Association, The Hardwood Flooring Handbook (Memphis, 1962), p. 3.

[5]Wood Floors for Dwellings, op, cit., p. 4.

[6]The Hardwood Flooring Handbook, op. cit., p. 4.

Strip flooring is the most widely used and generally the most economical.[7] It consists of flooring pieces cut in narrow strips of varying thickness and width, the most popular combination being a width of 2 1/4 inches with a thickness of 25/32 inch. This is known as the standard pattern.[8]

Tongue and grooved strip oak flooring in the standard pattern of both red and white types was obtained from a local lumber company. Twenty-eight test panels, half of red oak, half of white oak, were constructed by a local carpenter. Each panel measured 9" x 9" and consisted of four tongue and grooved strips fitted together and mounted on 1/4 inch thick plywood. The panels were cut into trapezoidal shapes to fit the circular surface of the Bowen Friction Tester. The test panels were attached to a plywood ring with plastic glue. The fourteen white oak panels were mounted on one side of the ring, alternating the grain lengthwise and crosswise. The red oak panels were placed in a like manner on the other half of the ring. The plywood ring was then secured to the table top of the friction tester.

Selection and Application of Floor Finishes

Seven wood floor finishes were selected for this study. They were obtained from four local paint and varnish dealers. Four were conventional finishes suggested by the National Oak Flooring Manufacturers Association for use on hardwood floors. These were floor seal, varnish, shellac,

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[7] Wood Floors for Dwellings, op. cit., p. 3.

[8] Ibid., p. 7.

and lacquer.[9] Two types of varnish, satin and gloss, were selected. The other two finishes selected, epoxy and polyurethane, were new products on the market. Panelists at a recent Paint and Wallpaper Association of America workshop described them as suitable for finishing wood floors due to their abrasion resistance and hardness.[10] A description of the floor finishes may be found in the Appendix.

The test panels were sanded and finished by a local floor finisher. A small power driven rotary disk sander was used for the sanding. Both No. 2 and No. 0 grain sandpaper were used. Dust was removed with a vacuum cleaner. A table of random numbers was used in assigning finishes to the test panels. Each finish was assigned to a lengthwise grain panel and a crosswise grain panel of both red and white oak. All the finishes were applied in the same manner. The directions of the manufacturers were used in determining the number of coatings to apply.

Selection of Heel Size and Material

Tuten found that the size of the heel is not a significant factor in determining the force of friction existing between the floor surface and the heel material.[11] Therefore a one-inch square of heel material was selected for this study.

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[9] The Hardwood Flooring Handbook, op. cit., p. 9.

[10] Jack Neslage, "Discussion of New Paints Drew Crowd," American Paint and Wallpaper Dealer, January, 1965, p. 34.

[11] Fern Tuten, "Testing of Skid Resistance of Smooth Floor Surfaces using Various Sizes of Rubber and Leather Shoe Heels" (unpublished Master's thesis, The Woman's College of the University of North Carolina, Greensboro, 1963), p. 53.

The shoe heel materials used were leather, nylon, rubber, Neolite, and rubber crepe. These were the most frequently used heel materials and all were available locally. Two brands of each heel material were acquired giving a total of ten samples to be tested.

Before testing, the surface finishes of the heel materials were removed with No. 400-A carborundum paper in order that the entire heel surface would come in contact with the flooring materials.

A table of random numbers was used to determine the order of testing heel materials.

Selection of Waxes

The floor finishes in this study were waxed with four wood floor waxes. These included a self polishing wax, a liquid, and a paste solvent base wax, and a paste wax carrying a slip resistant seal on the label. The self polishing wax selected was one of several of its type new on the market. The solvent base waxes selected were the best sellers on the local market, and the slip resistant wax was the only one of its kind that could be found locally. The order for testing the waxes was as follows: self polishing, liquid solvent, paste solvent, and paste skid resistant.

Selection of Weight Load

Results of a study completed in Australia of the pressures on the human foot in walking, revealed that the average maximum pressure exerted by the subjects was 25 pounds per square inch.[12] A similar study in England indicated that this pressure was 21 pounds per square inch.[13]

A preliminary test for this study using a 25 pound load on the heel material damaged the floor finish. Therefore a weight of 12 1/2 pounds was selected for use in testing.

III. TESTING PROCEDURE

New Floor Panels

For each test the circular table was revolved twice under the weighted heel platform. This provided for two determinations of each combination of materials.

Each of the five types of heel materials was tested in a different tract of the testing table. This gave a comparable testing surface for each heel material.

The combinations of test materials were tested first in a dry condition. Moisture was then added with the use of a spray bottle for testing the material in a wet condition.

Since there were duplicates of each of the five heel materials, ten tests of two determinations were made for both wet and dry conditions giving a total of twenty tests on the new floor panels.

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[12] T. S. Holden, and R. W. Muncey, "Pressures on the Human Foot During Walking," Australian Journal of Applied Science, III (1953), p.411.

[13] F. C. Harper, W. J. Warlow, and B. L. Clarke, The Forces Applied to the Floor by the Foot in Walking, National Building Studies Research Paper 32, Department of Scientific and Industrial Research, Building Research Station (London: Her Majesty's Stationery Office, 1961), p. 22.

Worn Floor Panels

The new floor surfaces were worn by an accelerated method using No. 400-A carborundum paper attached to the weight platform of the testing machine. The testing surface was revolved twenty times beneath the platform. Research on stairway safety in Michigan concluded from tests on shoe sole and tread materials that the coefficient of friction dropped off rapidly with repeated testing of new materials but that the coefficient of friction leveled off after 15-20 repetitive tests.[14]

The worn panels were tested in the same manner as the new panels. Both dry and wet tests were made giving a total of twenty tests on worn panels.

Waxed Floor Panels

The self polishing wax and the liquid solvent base wax were applied in accordance with an ASTM method for hand application.[15] The applicator was of cheesecloth, which had been washed to remove the sizing. The cheesecloth was cut into two-inch strips of four-ply cloth, trimmed to weigh .6 gram, and folded twice. The wax was measured into a pipet, 1.7 liters for each panel, and was placed onto the center of the test panel. The cheesecloth strip was placed over this and allowed

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[14] Agricultural Engineering Department of Michigan State University and North Central Farm Housing Committee. "The Cause and Nature of Stairway Falls," (Michigan Contributing Project Report for 1959), p. 2. (Mimeographed.)

[15] American Society for Testing Materials, "Tentative Methods for Application of Emulsion Floor Polishes to Substrates for Testing Purposes," Reprinted from Copyrighted 1956 Supplement to Book of ASTM Standards, Part 4 (ASTM Designation: D1436-56T), pp. 112-113.

to absorb the wax. The wax was distributed over the surface drawing the cheesecloth downward in separate strokes until the entire panel was covered. The cheesecloth was then placed in a stoppered weighing bottle and weighed on a balance scale. The weights of the 28 used applicators were not allowed to vary more than .15 gram. This assured, in as much as possible, that the panels had a uniform film thickness. The panels were allowed to dry for 18 to 24 hours before testing.

No standard method could be found for the application of the paste waxes. The amount of paste wax used on each panel was weighed prior to application and was equal in weight to the amount of the liquid wax used. In as much as possible the paste waxes were applied by the same method as the liquid waxes.

The liquid solvent base wax and both paste waxes required buffing. The self polishing did not. The buffing was done with an electric polisher which was held in one position while the test panels revolved underneath. Each panel was buffed five times with brushes and five times with buffer pads.

The testing procedure was identical to that of the new and worn test panels. Each wax was tested in a dry condition and with applied moisture giving a total of 80 tests for all four waxes.

After testing was completed on each wax, it was removed with a mineral spirit. Gloss measurements were taken and compared with measurements obtained on the unwaxed floor surfaces before wax application.

IV. METHOD OF DATA ANALYSIS

The data were analyzed as two separate experiments corresponding to wet and dry conditions of the tested materials.

Analysis of variance calculations were done on an IBM 1410 computer at North Carolina State University with advice and assistance from the Department of Experimental Statistics.

Each experiment was basically a factorial design. Wood floor finishes (7), type of oak flooring (2) and grain direction of oak flooring (2) required 28 test specimen (7 x 2 x 2 = 28). Each test speciman was considered an experimental unit in the analysis of main effects and interactions among these three factors. Two further factors - surface condition (6), and heel materials (5) were introduced in an essentially split plot manner. All combinations of these factors were tested on each of the 28 test specimen. Thus, the main effects and all interactions involving these latter two factors were not influenced by random variation among the test specimen.

One further feature of the design was that each heel material was represented by a sample from each of two different manufacturers.

The following hypotheses - with respect to force of friction values - were tested by means of F tests: (1) no differences among wood floor finishes; (2) no differences among surface conditions; (3) no differences among heel materials; (4) no differences between types of oak flooring; (5) no differences between grain direction; (6) no interactions among the five factors. The .01 significance level was used for all tests. Appropriate higher order interactions were used as error terms.

Coefficient of kinetic friction values were computed from the following formula:

$$\text{Coefficient of Kinetic Friction} = \frac{\text{Force of Friction}}{\text{Normal Force}}$$[16]

Hereafter coefficient of kinetic friction will be referred to as coefficient of friction.

Analyses of the data may be found in the following chapters.

[16] Madalyn Avery, Household Physics (New York: The MacMillan Company, 1956), p. 24.

CHAPTER IV

RESULTS OF MATERIALS TESTED IN A DRY AND WET CONDITION

The results of tests of skid resistance of wood floor finishes under varying surface conditions are presented in this chapter.

Sixty tests were made on the materials in a dry condition and sixty tests on the materials with moisture applied. The tests resulted in 6,720 measurements to be analyzed.

I. RESULTS OF MATERIALS TESTED IN A DRY CONDITION

Analysis of variance of the skid resistance of wood floor finishes under varying surface conditions in a dry condition is presented in Table I. Analysis of the data revealed highly significant differences among force of friction values for four of the five main effects. This lead to the rejection of the null hypotheses that there are no differences in force of friction values: (1) among wood floor finishes; (2) among surface conditions; (3) among heel materials; and (4) between oak types. The null hypothesis that there are no differences in force of friction values between grain directions of oak flooring was not rejected.

There were ten possible first-order interactions. Six of these were highly significant and the null hypothesis was rejected for each of the following significant first-order interactions:

Wood floor finishes by heel materials
Grain directions by wood floor finishes
Surface conditions by wood floor finishes
Surface conditions by oak types
Surface conditions by grain directions
Surface conditions by heel materials

TABLE I

ANALYSIS OF VARIANCE OF SKID RESISTANCE TESTS ON WOOD FLOOR FINISHES

(DRY)

Source of variation	Degrees of freedom	Mean square	F value
Wood floor finishes	6	195.11	35.282**
Oak types	1	147.36	26.647**
Grain directions	1	19.32	3.494
Wood floor finishes x oak types	6	4.46	.807
Wood floor finishes x grain directions	6	2.06	.373
Oak types x grain directions	1	3.41	.617
Wood floor finishes x oak types x grain directions (error)	6	5.53	
Heel materials	4	2223.27	23.429**
Manufacturers/heel materials (error)	5	94.89	
Wood floor finishes x heel materials	24	10.94	6.473**
Wood floor finishes x manufacturers/heel materials (error)	30	1.69	
Oak types x heel materials	4	6.23	11.125
Oak types x manufacturers/heel materials (error)	5	.56	
Grain directions x heel materials	4	4.31	33.154**
Grain directions x manufacturers/heel materials (error)	5	.13	
Wood floor finishes x oak types x heel materials	24	1.74	3.222**
Wood floor finishes x oak types x manufacturers/heel materials (error)	30	.54	
Wood floor finishes x grain directions x heel materials	24	1.26	5.25**
Wood floor finishes x grain directions x manufacturers/heel materials (error)	30	.24	
Oak types x grain directions x heel materials	4	2.81	6.854
Oak types x grain directions x manufacturers/heel materials (error)	5	.41	

**Significant at .01 level.

Table I (continued)

Source of variation	Degrees of freedom	Mean square	F value
Wood floor finishes x oak types x grain directions x heel materials	24	1.38	8.118**
Wood floor finishes x oak types x grain directions x manufacturers/heel materials (error)	30	.17	
Surface conditions	5	461.52	710.031**
Surface conditions x wood floor finishes	30	14.66	22.554**
Surface conditions x oak types	5	10.82	16.646**
Surface conditions x grain directions	5	6.42	9.877**
Surface conditions x wood floor finishes x oak types	30	2.51	3.862**
Surface conditions x wood floor finishes x grain directions	30	.90	1.385
Surface conditions x oak types x grain directions	5	.85	1.308
Surface conditions x wood floor finishes x oak types x grain directions (error)	30	.65	
Surface conditions x heel materials	20	61.80	4.286**
Surface conditions x manufacturers/ heel materials (error)	25	14.42	
Surface conditions x wood floor finishes x heel materials	120	1.79	3.442**
Surface conditions x wood floor finishes x manufacturers/heel materials (error)	150	.52	
Surface conditions x oak types x heel materials	20	1.70	2.742**
Surface conditions x oak types x manufacturers/heel materials (error)	25	.62	
Surface conditions x grain directions x heel materials	20	1.18	5.130**
Surface conditions x grain directions x manufacturers/heel materials (error)	25	.23	
Surface conditions x wood floor finishes x oak types x heel materials	120	.76	3.304**
Surface conditions x wood floor finishes x oak types x manufacturers/heel materials (error)	150	.23	

Table I (Continued)

Source of variation	Degrees of freedom	Mean square	F value
Surface conditions x wood floor finishes x grain directions x heel materials	120	.40	2.857**
Surface conditions x wood floor finishes x grain directions x manufacturers/heel materials (error)	150	.14	
Surface conditions x oak types x grain directions x heel materials	20	.42	1.68
Surface conditions x oak types x grain directions x manufacturers/ heel materials (error)	25	.25	
Surface conditions x wood floor finishes x oak types x grain directions x heel materials	120	.29	1.813**
Surface conditions x wood floor finishes x oak types x grain directions x manufacturers/heel materials (error)	150	.16	
Total	1679		

Six of the nine possible second-order interactions were highly significant, therefore the null hypothesis was rejected for each of the following:

Wood floor finishes by oak types and heel materials
Wood floor finishes by grain directions and heel materials
Wood floor finishes by oak types and grain directions
Surface conditions by wood floor finishes and heel materials
Surface conditions by oak types and heel materials
Surface conditions by grain directions and heel materials

Three third-order interactions were highly significant, and the null hypothesis was rejected for each significant third-order interaction:

Surface conditions by wood floor finishes, oak types and heel materials
Surface conditions by wood floor finishes, grain directions and heel materials
Wood floor finishes by oak types, grain directions and heel materials

The one fourth-order interaction was highly significant. Therefore the null hypothesis for surface conditions by wood floor finishes, grain directions, oak types and heel materials was rejected.

Coefficient of friction values have been used as a measure of skid resistance in previous studies. Therefore, coefficient of friction values were computed in this experiment to enable a comparison of the data on wood floor finishes with previous data on flooring materials collected on the same machine.

Analyses of the coefficient of friction values for the major significant interactions follow.

Wood Floor Finishes by Heel Materials

The lowest coefficient of friction for each of the seven finishes was obtained with the leather heel and the highest coefficient of friction with the rubber crepe heel material. The leather heel material consistently gave a coefficient of friction of less than .34 (Table II).

All other heel materials in combination with each finish gave coefficients of friction of higher than .44. Three heel materials, nylon, rubber, and Neolite did not test in the same order with each finish; but in each case the coefficients of friction were closely grouped. The coefficient of friction values for leather were substantially lower than for nylon, Neolite and rubber, and those for rubber crepe substantially higher.

There was a range in coefficient of friction of .36 with the rubber crepe heel from penetrating seal, the lowest ranking finish, to epoxy, the highest ranking finish. This was larger than the range with the other heel materials.

The penetrating seal floor finish gave the lowest, and epoxy the highest overall coefficient of friction. The seven finishes did not rank in the same order when tested with each heel materials, but the variations were generally slight.

Grain Directions by Heel Materials

The lengthwise grain direction gave a higher coefficient of friction with each heel material than did the crosswise grain direction (Table III). The most substantial difference in coefficient of friction values between the grain direction was with the nylon and rubber crepe heels. There were small differences with leather, rubber, and Neolite heel materials.

TABLE II

MEAN COEFFICIENTS OF KINETIC FRICTION OF WOOD FLOOR FINISHES

BY HEEL MATERIALS

(DRY)

Floor finish	Heel material					Mean of floor finishes
	Leather	Nylon	Rubber	Neolite	Rubber crepe	
Penetrating seal	.220	.447	.521	.520	.632	.468
Polyurethane	.214	.498	.570	.584	.753	.524
Satin varnish	.247	.488	.571	.569	.809	.537
Lacquer	.275	.563	.600	.630	.887	.591
Shellac	.326	.574	.606	.628	.966	.620
Gloss varnish	.334	.617	.647	.681	.953	.646
Epoxy	.333	.662	.655	.695	.989	.667
Mean of heel materials	.278	.550	.596	.615	.856	

TABLE III

MEAN COEFFICIENTS OF KINETIC FRICTION OF HEEL MATERIALS BY GRAIN DIRECTIONS (DRY)

Heel material	Grain direction		Mean of heel materials
	Crosswise	Lengthwise	
Leather	.277	.279	.278
Nylon	.527	.573	.550
Rubber	.592	.599	.596
Neolite	.612	.618	.615
Rubber crepe	.843	.868	.856
Mean of grain directions	.570	.588	

The heel materials ranked in the same order for both lengthwise and crosswise grain directions. Leather gave a coefficient of friction value of less than .28 for both. All other coefficient of friction values were above .52. Nylon, rubber, and Neolite were grouped in the .52-.62 range. These three materials ranked in the above order for tests in both grain directions. Rubber crepe gave the highest coefficient of friction with both grain directions.

Wood Floor Finishes by Heel Materials and Oak Types

In every case but one the white oak gave a higher coefficient of friction than the red oak (Table IV). Substantial differences between the red and white oak occurred when the finishes were tested with the nylon heel material and for the shellac finish with all heel materials except leather.

Wood Floor Finishes by Grain Directions and Heel Materials

The lengthwise grain direction more frequently gave a higher coefficient of friction than did the crosswise grain direction when tested with floor finishes and heel materials (Table V). The lengthwise grain gave a higher coefficient of friction for lacquer and shellac floor finishes and generally for gloss varnish and epoxy finishes. This was also true when testing was done with the nylon heel for each finish.

The crosswise grain was generally higher in coefficient of friction for the satin varnish finish and for four of the seven finishes tested with the leather heel material.

Few of the differences in coefficient of friction between the grain directions were large.

TABLE IV

MEAN COEFFICIENTS OF KINETIC FRICTION OF WOOD FLOOR FINISHES

BY HEEL MATERIALS AND OAK TYPES

(DRY)

Floor finish	Oak type	Heel material					Mean of floor finishes
		Leather	Nylon	Rubber	Neolite	Rubber crepe	
Penetrating seal	Red oak	.213	.390	.495	.462	.616	.435
	White oak	.226	.505	.546	.577	.649	.501
Polyurethane	Red oak	.212	.466	.550	.581	.726	.507
	White oak	.216	.530	.589	.588	.779	.541
Satin varnish	Red oak	.243	.440	.555	.556	.791	.517
	White oak	.250	.537	.586	.581	.828	.557
Lacquer	Red oak	.252	.555	.595	.606	.876	.577
	White oak	.297	.572	.605	.654	.898	.605
Shellac	Red oak	.322	.537	.555	.575	.913	.580
	White oak	.329	.612	.657	.681	1.018	.660
Gloss varnish	Red oak	.331	.604	.649	.645	.948	.635
	White oak	.336	.630	.645	.717	.958	.657
Epoxy	Red oak	.327	.613	.598	.666	.971	.635
	White oak	.339	.711	.712	.723	1.007	.698
Mean of heel materials		.278	.550	.596	.615	.856	

TABLE V

MEAN COEFFICIENTS OF KINETIC FRICTION OF WOOD FLOOR FINISHES BY GRAIN DIRECTIONS AND HEEL MATERIALS (DRY)

Wood floor finish and grain direction	Heel material					Mean of floor materials
	Leather	Nylon	Rubber	Neolite	Rubber crepe	
Penetrating seal						
Lengthwise	.217	.459	.513	.531	.633	.471
Crosswise	.222	.436	.529	.508	.632	.465
Polyurethane						
Lengthwise	.212	.511	.571	.576	.750	.524
Crosswise	.216	.485	.568	.592	.755	.523
Satin varnish						
Lengthwise	.246	.502	.561	.564	.809	.536
Crosswise	.247	.475	.581	.573	.809	.537
Lacquer						
Lengthwise	.282	.573	.600	.646	.915	.603
Crosswise	.267	.553	.599	.613	.859	.578
Shellac						
Lengthwise	.333	.603	.616	.648	.984	.637
Crosswise	.318	.545	.596	.608	.947	.603
Gloss varnish						
Lengthwise	.326	.654	.653	.703	.974	.662
Crosswise	.342	.580	.641	.659	.932	.631
Epoxy						
Lengthwise	.338	.709	.680	.660	1.008	.679
Crosswise	.328	.616	.630	.729	.970	.654
Mean of heel materials	.278	.550	.596	.615	.856	

Surface Conditions by Wood Floor Finishes

Waxing generally lowered the coefficients of friction of the wood floor finishes (Table VI). The liquid solvent base consistently showed the lowest, and the unwaxed conditions generally showed the highest coefficient of friction. The new condition was higher than the worn condition. The coefficient of friction of the polyurethane finish was higher with the self polishing wax than in the worn condition, but lower than in the new condition. The self polishing wax and the paste skid resistant wax raised the coefficient of friction of satin varnish.

Among the waxed conditions the self polishing wax gave the highest coefficient of friction.

In the worn and waxed conditions, there was little difference in coefficient of friction between the satin varnish and lacquer finish, and between the shellac and gloss varnish finishes. In the new condition substantial differences were noted between these finishes.

Penetrating seal showed the lowest and epoxy the highest coefficient of friction for the floor finishes under varying surface conditions. The ranking of the five middle finishes was not consistent for each surface condition, but the variation was not great. The difference in coefficient of friction from the penetrating seal to epoxy was substantially greater in the new condition than in the other conditions.

Surface Conditions by Oak Types

The white oak showed higher coefficients of friction than the red oak for all the surface conditions (Table VII). The differences were

TABLE VI

MEAN COEFFICIENTS OF KINETIC FRICTION OF WOOD FLOOR FINISHES IN VARIOUS SURFACE CONDITIONS (DRY)

Floor finish	Surface condition						Mean of floor finishes
	Unwaxed		Waxed				
	New	Worn	Self polishing wax	Paste skid resistant wax	Paste solvent base wax	Liquid solvent base wax	
Penetrating seal	.584	.547	.506	.416	.402	.354	.468
Polyurethane	.629	.572	.611	.510	.447	.373	.524
Satin varnish	.548	.553	.597	.585	.502	.436	.537
Lacquer	.784	.663	.576	.565	.517	.440	.591
Shellac	.797	.664	.630	.597	.541	.491	.620
Gloss varnish	.901	.676	.637	.613	.561	.490	.646
Epoxy	.906	.756	.651	.620	.562	.507	.667
Mean of surface condition	.735	.633	.601	.558	.504	.442	

TABLE VII

MEAN COEFFICIENTS OF KINETIC FRICTION OF VARIOUS SURFACE CONDITIONS ON WOOD FLOOR FINISHES BY OAK TYPES (DRY)

Surface condition	Oak type Red	Oak type White	Mean of surface conditions
Unwaxed			
New	.691	.779	.735
Worn	.589	.676	.633
Waxed			
Self polishing wax	.585	.617	.601
Paste skid resistant wax	.546	.570	.558
Paste solvent base wax	.494	.515	.504
Liquid solvent base wax	.426	.457	.442
Mean of oak types	.555	.603	

most substantial between the oak types in the unwaxed conditions, but not as great for the waxed conditions, all of which showed about the same difference. Waxing lowered the coefficients of friction.

The surface conditions ranked in the same order by oak type with the liquid solvent base wax lowest and the new condition highest.

The white oak showed a wider range in coefficient of friction than the red oak for all surface conditions.

Surface Conditions by Grain Directions

The lengthwise grain direction showed a higher coefficient of friction for all surface conditions except the paste skid resistant wax which showed a higher coefficient of friction in the crosswise grain direction (Table VIII).

The most substantial difference between lengthwise and crosswise grain was in the worn surface condition. Large differences were also shown in grain direction with the liquid solvent base wax and the new condition.

Waxing lowered the coefficient of friction for both grain directions. The new condition gave the highest, and the liquid solvent base wax the lowest coefficient of friction. Among the waxed conditions the self polishing wax gave the highest coefficient of friction.

The range in coefficient of friction from lowest to highest ranking finish was the same for both grain directions.

Wood Floor Finishes by Surface Conditions and Oak Types

With only two exceptions the white oak showed a higher coefficient of friction than did the red oak for the floor finishes tested under

TABLE VIII

MEAN COEFFICIENTS OF KINETIC FRICTION OF VARIOUS SURFACE CONDITIONS ON WOOD FLOOR FINISHES BY GRAIN DIRECTIONS

(DRY)

Surface condition	Grain direction		Mean of surface conditions
	Crosswise	Lengthwise	
Unwaxed			
New	.721	.749	.735
Worn	.606	.660	.633
Waxed			
Self polishing wax	.598	.605	.601
Paste skid resistant wax	.565	.551	.558
Paste solvent base wax	.504	.505	.504
Liquid solvent base wax	.428	.455	.442
Mean of grain directions	.570	.588	

various surface conditions (Table IX). In the unwaxed conditions substantial differences between the oak types were shown, but in the waxed conditions the differences were not as great.

In all cases but one the new condition showed the highest coefficient of friction. The exception was the satin varnish on red oak where the self polishing wax and the paste skid resistant wax gave higher values.

In several cases the self polishing wax condition showed higher coefficients of friction than the worn condition. This was noticed with polyurethane and satin varnish on both oak types and with shellac on the red oak where the paste skid resistant wax also gave a higher value than the worn condition.

The range in coefficient of friction from the lowest ranking finish (penetrating seal) to the highest (epoxy) was much greater for the unwaxed conditions than for the waxed conditions. In the worn condition much of this difference was accounted for by the low value of red and the high value of white oak. For the other conditions the oak type showed a similar difference from the low to the high ranking finish.

Surface Conditions by Heel Materials

The highest coefficient of friction for the leather, nylon, and rubber heel materials was found in the new condition, for the Neolite heel material in the worn condition and for the rubber crepe heel material with the self polishing wax (Table X).

The lowest coefficient of friction for the leather, nylon, and rubber heel materials was found with the liquid solvent base wax, for the Neolite heel material with the paste wax, and for the rubber crepe heel the worn condition.

TABLE IX

MEAN COEFFICIENTS OF KINETIC FRICTION OF WOOD FLOOR FINISHES BY OAK TYPES AND SURFACE CONDITIONS

(DRY)

Floor finish	Oak type	Surface condition: Unwaxed: New	Unwaxed: Worn	Waxed: Self polishing wax	Waxed: Paste skid resistant wax	Waxed: Paste solvent base wax	Waxed: Liquid solvent base wax	Mean of floor finishes
Penetrating seal	Red	.517	.484	.472	.410	.390	.337	.435
	White	.650	.609	.539	.421	.414	.371	.501
Polyurethane	Red	.608	.575	.604	.474	.439	.341	.507
	White	.650	.568	.619	.547	.454	.406	.541
Satin varnish	Red	.486	.521	.592	.590	.488	.424	.517
	White	.610	.584	.602	.580	.515	.449	.557
Lacquer	Red	.751	.650	.565	.551	.515	.430	.577
	White	.818	.675	.588	.580	.520	.450	.605
Shellac	Red	.722	.575	.603	.582	.524	.476	.580
	White	.871	.754	.658	.611	.558	.506	.660
Gloss varnish	Red	.918	.644	.633	.603	.541	.475	.635
	White	.884	.709	.642	.623	.581	.505	.657
Epoxy	Red	.839	.675	.628	.612	.559	.499	.635
	White	.972	.837	.674	.628	.565	.514	.698
Mean of surface conditions		.735	.633	.601	.558	.504	.442	

TABLE X

MEAN COEFFICIENTS OF KINETIC FRICTION
OF VARIOUS SURFACE CONDITIONS
ON WOOD FLOOR FINISHES
BY HEEL MATERIALS
(DRY)

Surface condition	Heel material					Mean of surface conditions
	Leather	Nylon	Rubber	Neolite	Rubber crepe	
Unwaxed						
New	.424	.818	.755	.744	.936	.735
Worn	.189	.693	.709	.816	.758	.633
Waxed						
Self polishing wax	.282	.528	.608	.637	.951	.601
Paste skid resistant wax	.321	.484	.566	.543	.875	.558
Paste solvent base wax	.286	.442	.478	.473	.843	.504
Liquid solvent base wax	.168	.335	.457	.478	.770	.442
Mean of heel materials	.278	.550	.596	.615	.856	

Wood Floor Finishes by Surface Conditions and Heel Materials

In general, waxing lowered the coefficients of friction of the wood floor finishes (Table XI). The new condition generally gave the highest coefficient of friction except when the leather heel material was tested with the penetrating seal, and polyurethane floor finishes, and when the satin varnish finish was tested with all heel materials.

Coefficients of friction were relatively high for all floor finishes in the worn condition with the nylon, rubber, and Neolite heel materials, but relatively low with the leather and rubber crepe heel materials. For many finishes in a worn condition, the rubber crepe heel tested lower than the nylon, rubber, and Neolite heel materials. In other analyses rubber crepe consistently gave higher coefficient of friction values than the other heel materials.

Finishes waxed with the liquid solvent base wax generally showed the lowest coefficients of friction. All finishes waxed with the paste solvent base wax also gave relatively low coefficients of friction with leather and rubber crepe heel materials.

Summary of Materials Tested in a Dry Condition

Analysis of the wood floor finishes showed penetrating seal to have the least skid resistance with a mean coefficient of friction of .468. The epoxy finish had the greatest skid resistance with a mean coefficient of friction of .667. Penetrating seal always ranked lowest and epoxy highest in combination with all other factors. The polyurethane, satin varnish, lacquer, shellac, and gloss varnish did not

TABLE XI

MEAN COEFFICIENTS OF KINETIC FRICTION OF WOOD FLOOR FINISHES IN VARIOUS SURFACE CONDITIONS BY HEEL MATERIALS

(DRY)

Wood floor finish	Surface condition	Heel material					Mean of floor materials
		Leather	Nylon	Rubber	Neolite	Rubber crepe	
Penetrating seal	Unwaxed						
	New	.234	.652	.671	.596	.765	.584
	Worn	.179	.603	.654	.706	.592	.547
	Waxed						
	Self polishing wax	.296	.432	.547	.557	.695	.506
	Paste skid resistant wax	.254	.336	.453	.449	.586	.416
	Paste solvent base wax	.215	.387	.401	.410	.598	.402
	Liquid solvent base wax	.140	.273	.400	.400	.558	.354
Polyurethane	Unwaxed						
	New	.221	.744	.733	.667	.781	.629
	Worn	.168	.572	.640	.760	.718	.572
	Waxed						
	Self polishing wax	.268	.527	.618	.691	.952	.611
	Paste skid resistant wax	.253	.446	.555	.526	.771	.510
	Paste solvent base wax	.249	.424	.450	.427	.685	.447
	Liquid solvent base wax	.126	.275	.421	.436	.609	.373
Satin varnish	Unwaxed						
	New	.252	.571	.593	.558	.766	.548
	Worn	.173	.580	.636	.737	.638	.553
	Waxed						
	Self polishing wax	.275	.518	.628	.625	.938	.597
	Paste skid resistant wax	.342	.504	.603	.528	.949	.585
	Paste solvent base wax	.288	.432	.498	.480	.811	.502
	Liquid solvent base wax	.149	.326	.468	.484	.754	.436

Table XI (Continued)

Wood floor finish	Surface condition	Heel material					Mean of floor materials
		Leather	Nylon	Rubber	Neolite	Rubber crepe	
Lacquer	Unwaxed						
	New	.448	.899	.772	.839	.963	.784
	Worn	.187	.729	.773	.838	.787	.663
	Waxed						
	Self polishing wax	.264	.505	.590	.599	.925	.576
	Paste skid resistant wax	.307	.485	.547	.565	.922	.565
	Paste solvent base wax	.281	.452	.476	.484	.893	.517
	Liquid solvent base wax	.161	.311	.440	.453	.833	.440
Shellac	Unwaxed						
	New	.556	.868	.766	.722	1.072	.797
	Worn	.204	.690	.703	.816	.908	.664
	Waxed						
	Self polishing wax	.295	.540	.612	.644	1.060	.630
	Paste skid resistant wax	.363	.509	.578	.588	.945	.597
	Paste solvent base wax	.328	.450	.485	.493	.947	.541
	Liquid solvent base wax	.208	.388	.494	.504	.862	.491
Gloss varnish	Unwaxed						
	New	.636	.972	.869	.968	1.060	.901
	Worn	.211	.769	.743	.895	.762	.676
	Waxed						
	Self polishing wax	.284	.572	.638	.658	1.034	.637
	Paste skid resistant wax	.362	.546	.615	.544	.995	.613
	Paste solvent base wax	.322	.477	.524	.509	.973	.561
	Liquid solvent base wax	.188	.365	.492	.512	.893	.490

Table XI (Continued)

Wood floor finish	Surface condition	Heel material: Leather	Nylon	Rubber	Neolite	Rubber crepe	Mean of floor materials
Epoxy	Unwaxed						
	New	.620	1.021	.833	.859	1.146	.906
	Worn	.200	.906	.813	.960	.901	.756
	Waxed						
	Self polishing wax	.291	.603	.626	.686	1.049	.651
	Paste skid resistant wax	.364	.562	.614	.599	.960	.620
	Paste solvent base wax	.320	.473	.511	.510	.996	.562
	Liquid solvent base wax	.204	.408	.484	.554	.882	.507
Mean of heel materials		.278	.550	.596	.615	.856	

always rank in the same order for all combinations of materials although the variation was not great. The increase in mean coefficient of friction was gradual from the lowest ranking to the highest ranking finish. The analysis showed greater differences in coefficient of friction for the wood floor finishes in combination with the heel materials than for the wood floor finish under varying surface conditions.

Analysis of heel materials showed that leather had a mean coefficient of friction of .278 (the lowest of the heel materials) and rubber crepe a mean coefficient of friction of.856 (the highest of the heel materials). The mean coefficients of friction of nylon, rubber, and Neolite were .550, .596, and .615, respectively. In combination with the other factors, the leather heel material always ranked substantially lower and the rubber crepe material substantially higher than the nylon, rubber, and Neolite heel materials. The nylon, rubber and Neolite heel materials did not always rank in the same order when tested in combination with all other factors; however, their coefficients of friction were usually similar and always ranked between leather and rubber crepe.

The analysis of the surface conditions showed the mean coefficients of friction of the unwaxed conditions to rank highest. The mean coefficient of friction of the new condition was .735, and of the worn condition, .633. The self polishing wax ranked highest among the waxed conditions with a mean coefficient of friction of .601, while the liquid solvent base wax ranked lowest with a mean coefficient of friction of .442. Generally, waxing lowered the coefficient of friction of the floor finishes; however, with several combinations of factors, the analysis showed that skid resistant paste wax and the self polishing wax gave a higher coefficient of friction than the unwaxed conditions. The analysis showed a greater range in coefficient of friction for the surface conditions in combination with the heel materials than in combination with the wood floor finishes.

Analysis of the oak types showed white oak with a mean coefficient of friction of .603 and red oak with a mean coefficient of friction of .555. White oak consistently ranked higher than red oak for all combinations of materials. In several analyses the differences between the oak types was appreciable. The differences were greatest in the unwaxed conditions for the nylon heel material and with the shellac floor finish.

Analysis of the grain direction showed that the lengthwise grain had a higher coefficient of friction more often than the crosswise grain. The analysis for grain direction was, however, not significant, and differences noted in coefficient of friction between the grain directions were not substantial.

II. RESULTS OF MATERIALS TESTED WITH APPLIED MOISTURE

Analysis of variance of wood floor finishes under varying surface conditions with moisture applied is presented in Table XII. Analysis of the data revealed highly significant differences among force of friction values for four of the five main effects. This lead to rejection of the null hypotheses that there are no differences in force of friction values: (1) among wood floor finishes; (2) among heel materials; (3) among surface conditions applied to wood floor finishes and; (4) between grain directions of oak flooring.

TABLE XII

ANALYSIS OF VARIANCE OF SKID RESISTANCE TESTS ON WOOD FLOOR FINISHES (MOISTURE APPLIED)

Source of variation	Degrees of freedom	Mean square	F value
Wood floor finishes	6	26.23	19.4296**
Oak types	1	.10	.074
Grain directions	1	19.07	14.1259**
Wood floor finishes x oak types	6	7.88	5.837
Wood floor finishes x grain directions	6	2.33	1.7259
Oak types x grain directions	1	.74	.5481
Wood floor finishes x oak types x grain directions (error)	6	1.35	
Heel materials	4	2067.93	12.3186**
Manufacturers/heel materials (error)	5	167.87	
Wood floor finishes x heel materials	24	11.03	16.4626**
Wood floor finishes x manufacturers/ heel materials (error)	30	.67	
Oak types x heel materials	4	4.92	6.074
Oak types x manufacturers/heel materials (error)	5	.81	
Grain directions x heel materials	4	7.35	5.5263
Grain directions x manufacturers/heel materials (error)	5	1.33	
Wood floor finishes x oak types x heel materials	24	3.84	7.3846**
Wood floor finishes x oak types x manufacturers/heel materials (error)	30	.52	
Wood floor finishes x grain directions x heel materials	24	1.21	3.4571**
Wood floor finishes x grain directions x manufacturers/heel materials (error)	30	.35	
Oak types x grain directions x heel materials	4	1.21	13.4444**
Oak types x grain directions x manufacturers/heel materials (error)	5	.09	
Wood floor finishes x oak types x grain directions x heel materials	24	.44	.5789
Wood floor finishes x oak types x grain directions x manufacturers/ heel materials (error)	30	.76	

**Significant at .01 level.

Table XII (Continued)

Source of variation	Degrees of freedom	Mean square	F Value
Surface conditions	5	660.77	2753.2083**
Surface conditions x wood floor finishes	30	5.05	21.0416
Surface conditions x oak types	5	2.60	10.8333**
Surface conditions x grain directions	5	1.98	8.25**
Surface conditions x wood floor finishes x oak types	30	1.50	6.25**
Surface conditions x wood floor finishes x grain directions	30	.27	1.125
Surface conditions x oak types x grain directions	5	.30	1.25
Surface conditions x wood floor finishes x oak types x grain directions (error)	30	.24	
Surface conditions x heel materials	20	50.83	9.6451**
Surface conditions x manufacturers/ heel materials (error)	25	5.27	
Surface conditions x wood floor finishes x heel materials	120	1.31	2.5686**
Surface conditions x wood floor finishes x manufacturers/heel materials (error)	150	.51	
Surface conditions x oak types x heel materials	20	.62	.7654
Surface conditions x oak types x manufacturers/heel materials (error)	25	.81	
Surface conditions x grain directions x heel materials	20	.59	1.4047
Surface conditions x grain directions x manufacturers/heel materials (error)	25	.42	
Surface conditions x wood floor finishes x oak types x heel materials	120	.42	1.68**
Surface conditions x wood floor finishes x oak types x manufacturers/heel materials (error)	150	.25	
Surface conditions x wood floor finishes x grain directions x heel materials	120	.21	1.75**
Surface conditions x wood floor finishes x grain directions x manufacturers/heel materials (error)	150	.12	

Table XII (Continued)

Source of variation	Degrees of freedom	Mean square	F value
Surface conditions x oak types x grain directions x heel materials	20	.24	4.0**
Surface conditions x oak types x grain directions x manufacturers/heel materials (error)	25	.06	
Surface conditions x wood floor finishes x oak types x grain directions x heel materials	120	.23	1.9166**
Surface conditions x wood floor finishes x oak types x grain directions x manufacturers/heel materials (error)	150	.12	
Total	1679		

The null hypothesis that there are no differences between oak types was not rejected.

There were ten possible first-order interactions. Five of these were highly significant and the null hypothesis was rejected for each of the following first-order interactions:

Wood floor finishes by heel materials
Surface conditions by wood floor finishes
Surface conditions by oak types
Surface conditions by grain directions
Surface conditions by heel materials

There were nine possible second-order interactions. Five of these were highly significant and the null hypotheses were rejected for the following second-order interactions:

Wood floor finishes by oak types and heel materials
Wood floor finishes by grain directions and heel materials
Oak types by grain directions and heel materials
Surface conditions by wood floor finishes and oak types
Surface conditions by wood floor finishes and heel materials

Three of the four possible third-order interactions were highly significant and the null hypotheses were rejected for these:

Surface conditions by wood floor finishes, oak types and heel materials
Surface conditions by wood floor finishes, grain directions and heel materials
Surface conditions by oak types, grain directions and heel materials

The one fourth-order interaction was highly significant. Therefore the null hypothesis for surface conditions by wood floor finishes, oak types, grain directions, and heel materials was rejected.

Coefficient of friction values were computed for the major significant interactions. The analyses of the coefficient of friction values with moisture applied follow.

Wood Floor Finishes by Heel Materials

Each finish with moisture applied gave the lowest coefficient of friction with the leather heel material and the highest with the rubber crepe heel material (Table XIII). The rubber, Neolite, and nylon heel materials showed similar coefficients of friction for each finish but did not always rank in the same order.

Epoxy generally was the lowest ranking floor finish and lacquer the highest. However, when the finishes were tested with the leather heel material, the satin varnish finish gave the lowest coefficient of friction and the penetrating seal finish the highest. With the rubber crepe heel material the penetrating seal finish ranked lowest. Variations were greater with the leather and rubber crepe heel materials over the finishes than with the other heel materials.

The range in coefficient of friction from the lowest to the highest ranking finish for the leather heel material was substantially greater than for the other heel materials. A lower range in coefficient of friction was shown with penetrating seal than for the other finishes.

Wood Floor Finishes by Heel Materials and Oak Types

The finished red oak gave a higher coefficient of friction than the white oak in the majority of cases with moisture applied (Table XIV). Red oak finished in gloss varnish was higher over all heel materials. Epoxy, polyurethane, and satin varnish gave higher friction values on red than on white oak for four of the five heel materials. The white oak ranked higher for the penetrating seal and lacquer floor finishes.

TABLE XIII

MEAN COEFFICIENTS OF KINETIC FRICTION OF WOOD FLOOR FINISHES BY HEEL MATERIALS (MOISTURE APPLIED)

Wood floor finish	Heel material					Mean of floor finishes
	Leather	Rubber	Neolite	Nylon	Rubber crepe	
Epoxy	.167	.380	.394	.428	.730	.420
Polyurethane	.193	.393	.420	.395	.802	.441
Shellac	.233	.397	.395	.417	.766	.442
Satin varnish	.163	.408	.433	.419	.791	.443
Gloss varnish	.189	.401	.451	.452	.769	.452
Penetrating seal	.378	.433	.461	.446	.724	.488
Lacquer	.217	.457	.486	.486	.811	.491
Mean of heel materials	.220	.410	.434	.435	.770	

TABLE XIV

MEAN COEFFICIENTS OF KINETIC FRICTION OF WOOD FLOOR FINISHES
BY HEEL MATERIALS AND OAK TYPES
(MOISTURE APPLIED)

Floor finish and oak type	Heel material					Mean of floor materials
	Leather	Rubber	Neolite	Nylon	Rubber crepe	
Epoxy						
Red oak	.161	.404	.425	.441	.737	.434
White oak	.173	.356	.363	.415	.723	.406
Polyurethane						
Red oak	.244	.401	.428	.404	.743	.444
White oak	.142	.385	.412	.387	.862	.437
Shellac						
Red oak	.215	.404	.419	.432	.710	.436
White oak	.250	.389	.372	.402	.822	.447
Satin varnish						
Red oak	.185	.420	.435	.407	.812	.452
White oak	.142	.396	.431	.431	.770	.434
Gloss varnish						
Red oak	.190	.419	.456	.455	.804	.465
White oak	.188	.383	.447	.448	.734	.440
Penetrating seal						
Red oak	.355	.418	.434	.422	.685	.463
White oak	.402	.447	.489	.470	.763	.514
Lacquer						
Red oak	.241	.438	.467	.465	.786	.479
White oak	.192	.475	.505	.507	.836	.503
Mean of heel materials	.220	.410	.434	.435	.770	

The range in coefficient of friction for each heel material over the floor finishes was much higher for white oak than for red oak.

Wood Floor Finishes by Heel Materials and Grain Directions

The lengthwise grain showed higher coefficients of friction than the crosswise grain especially with the leather, nylon, and rubber crepe heel materials and with the shellac, gloss varnish, and penetrating seal finishes when moisture was applied (Table XV). These differences between the grain directions were not substantial.

Wood Floor Finishes by Surface Conditions

Waxing generally lowered the coefficient of friction of the wood floor finishes with moisture applied, with the exception of the self polishing wax which gave a higher coefficient of friction than the new condition with all finishes except shellac and lacquer. The self polishing wax gave the highest coefficient of friction when used with the epoxy finish (Table XVI).

The worn tested higher than the new condition for all finishes except epoxy and shellac.

The paste solvent base wax gave the lowest coefficient of friction for all finishes except gloss varnish. The paste and liquid solvent base wax and the skid resistant wax all tested substantially lower for all finishes than the self polishing wax and the unwaxed conditions.

No one finish was consistently lower or higher in coefficient of friction than the other finishes for all the surface conditions tested. The epoxy gave the lowest coefficient of friction for three surface conditions and the lacquer finish gave the highest coefficient for three surface conditions.

TABLE XV

MEAN COEFFICIENTS OF KINETIC FRICTION OF WOOD FLOOR FINISHES BY GRAIN DIRECTIONS AND HEEL MATERIALS (MOISTURE APPLIED)

Wood floor finish and grain direction	Heel material					Mean of floor materials
	Leather	Rubber	Neolite	Nylon	Rubber crepe	
Epoxy						
Lengthwise	.189	.367	.383	.429	.759	.426
Crosswise	.145	.393	.405	.426	.701	.414
Polyurethane						
Lengthwise	.200	.388	.406	.398	.806	.439
Crosswise	.186	.398	.434	.392	.799	.442
Shellac						
Lengthwise	.252	.402	.413	.444	.777	.458
Crosswise	.213	.391	.378	.390	.755	.426
Satin varnish						
Lengthwise	.172	.397	.415	.421	.822	.446
Crosswise	.155	.419	.450	.416	.759	.440
Gloss varnish						
Lengthwise	.224	.406	.454	.474	.813	.474
Crosswise	.154	.396	.449	.430	.725	.431
Penetrating seal						
Lengthwise	.389	.446	.466	.451	.717	.494
Crosswise	.368	.419	.457	.441	.730	.483
Lacquer						
Lengthwise	.233	.440	.482	.486	.863	.501
Crosswise	.201	.473	.490	.486	.759	.482
Mean of heel materials	.220	.410	.434	.435	.770	

TABLE XVI

MEAN COEFFICIENTS OF KINETIC FRICTION OF WOOD FLOOR FINISHES
IN VARIOUS SURFACE CONDITIONS
(MOISTURE APPLIED)

Floor finish	Surface condition						Mean of floor finishes
	Unwaxed		Waxed				
	New	Worn	Self polishing wax	Paste skid resistant wax	Liquid solvent base wax	Paste solvent base wax	
Epoxy	.506	.504	.520	.388	.304	.296	.420
Polyurethane	.495	.560	.554	.390	.346	.299	.441
Shellac	.548	.531	.523	.389	.336	.323	.442
Satin varnish	.517	.568	.549	.401	.331	.291	.443
Gloss varnish	.555	.580	.559	.413	.304	.305	.452
Penetrating seal	.625	.638	.631	.371	.338	.329	.488
Lacquer	.609	.671	.570	.428	.354	.315	.491
Mean of surface conditions	.551	.579	.558	.397	.330	.308	

Surface Conditions by Oak Types

The white oak gave a higher coefficient of friction than the red oak for four of the surface conditions with moisture applied (Table XVII). The red oak was higher in the new condition and with the self polishing wax. The differences were not appreciable in any case.

The worn condition gave the highest coefficient of friction for both red and white oak. Waxing lowered the coefficient of friction except for the self polishing wax which gave a higher value than the new condition for both oak types.

The solvent base paste wax gave the lowest coefficient of friction for both oak types.

Surface Conditions by Grain Directions

With applied moisture, the lengthwise grain direction gave a higher coefficient of friction than the crosswise grain for all surface conditions except for the worn condition in which case the coefficient of friction was equal for the grain directions (Table XVIII).

The surface conditions ranked in the same order for each grain direction with the paste solvent base wax giving the lowest coefficient of friction, and the worn condition giving the highest coefficient of friction. Waxing lowered the coefficientsof friction except for the self polishing wax which gave a higher coefficient of friction than the new condition.

Wood Floor Finishes by Oak Types and Surface Conditions

Neither type of oak gave consistently higher coefficients of friction than the other for all finishes by surface conditions with

TABLE XVII

MEAN COEFFICIENTS OF KINETIC FRICTION
OF VARIOUS SURFACE CONDITIONS
ON WOOD FLOOR FINISHES
BY OAK TYPES
(MOISTURE APPLIED)

Surface condition	Oak type		Mean of surface conditions
	Red	White	
Unwaxed			
New	.561	.540	.551
Worn	.578	.580	.579
Waxed			
Self polishing wax	.565	.551	.558
Paste skid resistant wax	.388	.406	.397
Liquid solvent base wax	.326	.335	.330
Paste solvent base wax	.302	.314	.308
Mean of oak types	.453	.454	

TABLE XVIII

MEAN COEFFICIENTS OF KINETIC FRICTION
OF VARIOUS SURFACE CONDITIONS
ON WOOD FLOOR FINISHES
BY GRAIN DIRECTIONS
(MOISTURE APPLIED)

Surface condition	Grain direction		Mean of surface conditions
	Crosswise	Lengthwise	
Unwaxed			
New	.548	.553	.551
Worn	.579	.579	.579
Waxed			
Self polishing wax	.553	.564	.558
Paste skid resistant wax	.381	.413	.397
Liquid solvent base wax	.318	.342	.330
Paste solvent base wax	.293	.323	.308
Mean of grain directions	.445	.462	

moisture applied (Table XIX). With the penetrating seal finish, the white oak was higher for all the surface conditions. With the gloss varnish finish, the red oak was higher than white oak for all the surface conditions.

The unwaxed conditions showed appreciable difference in coefficient of friction from the lowest ranking floor finish to the highest. This was due to the greater range in coefficient of friction for the white oak.

Surface Conditions by Heel Materials

With moisture applied the coefficients of friction were lower for waxed wood floor finishes tested with three heel materials - leather, rubber, and nylon - than for unwaxed wood floor finishes tested with these same heel materials (Table XX). With the Neolite heel material, the coefficients of friction were lower in waxed conditions than in unwaxed conditions except for the self polishing wax which gave a higher coefficient of friction than the new condition. With the rubber crepe heel material, the self polishing wax and the paste skid resistant wax on wood floor finishes gave higher coefficients of friction than the unwaxed condition.

The paste solvent base wax gave the lowest coefficient of friction for all heel materials except leather. With leather the paste skid resistant wax gave the lowest coefficient of friction. The paste skid resistant wax gave a very low relative coefficient of friction with the leather heel material and a very high relative coefficient of friction with the rubber crepe heel material.

TABLE XIX

MEAN COEFFICIENTS OF KINETIC FRICTION OF WOOD FLOOR FINISHES
BY OAK TYPES AND SURFACE CONDITIONS
(MOISTURE APPLIED)

Floor finish	Oak type	Surface Condition: Unwaxed: New	Surface Condition: Unwaxed: Worn	Surface Condition: Waxed: Self polishing wax	Surface Condition: Waxed: Paste skid resistant wax	Surface Condition: Waxed: Liquid solvent base wax	Surface Condition: Waxed: Paste solvent base wax	Mean of floor materials
Epoxy	Red	.547	.542	.548	.384	.289	.293	.434
	White	.464	.467	.493	.392	.320	.300	.406
Polyurethane	Red	.515	.557	.581	.379	.336	.295	.444
	White	.474	.563	.528	.400	.357	.303	.437
Shellac	Red	.574	.536	.533	.366	.312	.296	.436
	White	.522	.526	.514	.412	.360	.350	.447
Satin varnish	Red	.514	.566	.576	.402	.350	.303	.452
	White	.520	.570	.522	.400	.311	.280	.434
Gloss varnish	Red	.588	.592	.570	.418	.314	.306	.465
	White	.521	.567	.548	.407	.294	.303	.440
Penetrating seal	Red	.597	.613	.591	.348	.323	.306	.463
	White	.654	.663	.670	.393	.353	.352	.514
Lacquer	Red	.592	.640	.556	.415	.357	.317	.479
	White	.627	.702	.585	.441	.350	.312	.503
Mean of surface conditions		.551	.579	.558	.397	.330	.308	

TABLE XX

MEAN COEFFICIENTS OF KINETIC FRICTION OF VARIOUS SURFACE CONDITIONS ON WOOD FLOOR FINISHES BY HEEL MATERIALS (MOISTURE APPLIED)

Surface condition	Heel material					Mean of surface conditions
	Leather	Rubber	Neolite	Nylon	Rubber crepe	
Unwaxed						
New	.360	.524	.543	.605	.721	.551
Worn	.256	.589	.610	.600	.839	.579
Waxed						
Self polishing wax	.215	.511	.564	.548	.952	.558
Paste skid resistant wax	.150	.323	.335	.319	.858	.397
Liquid solvent base wax	.165	.260	.278	.270	.679	.330
Paste solvent base wax	.175	.252	.276	.266	.572	.308
Mean of heel materials	.220	.410	.434	.435	.770	

The rubber crepe heel material gave consistently higher coefficients of friction and the leather heel material gave consistently lower coefficients of friction than the other heel materials for all surface conditions. The rubber, Neolite, and nylon heel materials had similar coefficient of friction values for each surface condition but they did not always rank in the same order.

Wood Floor Finishes by Surface Conditions and Heel Materials

Waxing generally lowered the coefficient of friction of all the wood floor finishes tested with the leather, rubber, Neolite, and nylon heel materials with applied moisture (Table XXI). With the rubber crepe heel material, the paste skid resistant wax and the self polishing wax raised the coefficient of friction.

The paste and liquid solvent base waxes generally gave the lowest coefficient of friction values. An exception was noted with the leather heel material and skid resistant polish combination which tended to give the lowest coefficient of friction for all finishes.

Of the waxes, the self polishing wax gave the highest coefficient of friction. In the unwaxed condition the new gave a higher coefficient of friction than the worn condition when tested with the leather heel material and generally with the nylon heel material. However, the opposite was true for tests with the rubber, Neolite, and rubber crepe heel materials.

Great variation was noticed with the rubber crepe heel for the surface conditions with all finishes except penetrating seal. With the penetrating seal finish, the leather heel material gave relatively high

TABLE XXI

MEAN COEFFICIENTS OF KINETIC FRICTION OF WOOD FLOOR FINISHES
IN VARIOUS SURFACE CONDITIONS BY HEEL MATERIALS
(MOISTURE APPLIED)

Wood floor finish	Surface condition	Heel material: Leather	Rubber	Neolite	Nylon	Rubber crepe	Mean of floor materials
Epoxy	Unwaxed						
	New	.323	.507	.468	.589	.640	.506
	Worn	.183	.520	.526	.566	.727	.504
	Waxed						
	Self polishing wax	.148	.465	.518	.539	.932	.520
	Paste skid resistant wax	.106	.314	.327	.327	.866	.388
	Liquid solvent base wax	.107	.236	.259	.270	.648	.304
	Paste solvent base wax	.136	.239	.265	.275	.567	.296
Polyurethane	Unwaxed						
	New	.305	.463	.498	.508	.700	.495
	Worn	.240	.560	.567	.556	.875	.560
	Waxed						
	Self polishing wax	.189	.530	.563	.514	.974	.554
	Paste skid resistant wax	.120	.301	.332	.293	.903	.390
	Liquid solvent base wax	.155	.267	.285	.254	.772	.346
	Paste solvent base wax	.148	.238	.274	.247	.589	.299
Shellac	Unwaxed						
	New	.420	.552	.488	.577	.705	.548
	Worn	.241	.541	.523	.542	.807	.531
	Waxed						
	Self polishing wax	.216	.480	.521	.506	.894	.523
	Paste skid resistant wax	.144	.310	.317	.322	.850	.389
	Liquid solvent base wax	.176	.248	.272	.284	.701	.336
	Paste solvent base wax	.199	.251	.251	.273	.640	.323

Table XXI (Continued)

Wood floor finish	Surface condition	Heel material					Mean of floor materials
		Leather	Rubber	Neolite	Nylon	Rubber crepe	
Satin varnish	Unwaxed						
	New	.284	.499	.529	.540	.731	.517
	Worn	.190	.595	.626	.582	.846	.568
	Waxed						
	Self polishing wax	.146	.522	.550	.564	.961	.549
	Paste skid resistant wax	.110	.332	.337	.317	.910	.401
	Liquid solvent base wax	.119	.262	.275	.261	.737	.331
	Paste solvent base wax	.132	.237	.279	.248	.561	.291
Gloss varnish	Unwaxed						
	New	.335	.513	.550	.665	.711	.555
	Worn	.222	.580	.666	.617	.815	.580
	Waxed						
	Self polishing wax	.167	.507	.581	.554	.986	.559
	Paste skid resistant wax	.124	.333	.355	.335	.917	.413
	Liquid solvent base wax	.122	.233	.275	.267	.623	.304
	Paste solvent base wax	.164	.242	.280	.274	.562	.305
Penetrating seal	Unwaxed						
	New	.485	.557	.605	.630	.847	.625
	Worn	.463	.599	.629	.619	.881	.638
	Waxed						
	Self polishing wax	.428	.573	.644	.620	.889	.631
	Paste skid resistant wax	.307	.311	.309	.294	.632	.371
	Liquid solvent base wax	.318	.274	.284	.248	.564	.338
	Paste solvent base wax	.268	.283	.298	.266	.528	.329

Table XXI (Continued)

Wood floor finish	Surface condition	Heel material					Mean of floor materials
		Leather	Rubber	Neolite	Nylon	Rubber	
Lacquer	Unwaxed						
	New	.366	.577	.660	.728	.715	.609
	Worn	.250	.731	.734	.718	.921	.671
	Waxed						
	Self polishing wax	.211	.502	.568	.541	1.031	.570
	Paste skid resistant wax	.142	.357	.368	.344	.930	.428
	Liquid solvent base wax	.155	.299	.298	.304	.711	.354
	Paste solvent base wax	.176	.273	.286	.281	.558	.315
Mean of heel materials		.220	.410	.434	.435	.770	

coefficients of friction, while the rubber crepe heel gave relatively low coefficients of friction compared with other finish and heel material combinations.

The differences in coefficient of friction among the surface conditions with the leather heel were low compared to differences with other heel materials for all finishes except the shellac floor finish. Substantial differences were shown among the surface conditions for the lacquer finish for all heel materials except leather.

Summary of Materials Tested with Applied Moisture

The analysis of wood floor finishes with moisture applied showed that epoxy had the lowest mean coefficient of friction (.420), and lacquer had the highest mean coefficient of friction (.491). However, in combination with other materials, epoxy did not always rank lowest nor did lacquer always rank highest. There was no set pattern of ranking of the seven floor finishes tested in combination with the other factors. The mean coefficients of friction for the finishes showed a small range (.420 - .491). The polyurethane, shellac, satin varnish, and gloss varnish gave similar mean coefficients of friction. The analysis showed greater differences in coefficient of friction for the wood floor finishes in combination with the heel materials than for the wood floor finishes under varying surface conditions.

The analysis for heel materials showed leather to be the least skid resistant with a mean coefficient of friction of .220, and rubber crepe to be the most skid resistant with a mean coefficient of friction of .770. Rubber, Neolite and nylon heel materials gave similar mean coefficients of friction, .410, .434, .435, respectively. In combination with the other factors tested the coefficient of friction always ranked lowest for leather and highest for rubber crepe. There was a wide range in their coefficients of friction. The rubber, Neolite, and nylon heel materials always ranked in the middle but not always in the same order.

Analysis of the surface conditions with applied moisture showed the worn unwaxed condition to give the highest mean coefficient of friction. The mean coefficient of friction of the new unwaxed condition was .551, and the mean coefficient of friction of the self polishing wax was .558. The mean coefficients of friction of the other three waxes were lower, with the paste solvent base wax the lowest (.308). Throughout the analysis the unwaxed conditions and the self polishing wax gave appreciably higher coefficients of friction than the paste skid resistant wax and the liquid and paste solvent base waxes with the exception of the paste skid resistant wax when tested with the rubber crepe heel material. This combination gave a coefficient of friction comparable with the coefficient of friction of the unwaxed conditions. The analysis showed a greater variability in coefficient of friction for the surface conditions in combination with the heel materials than for the surface conditions tested with the wood floor finishes.

Analysis of the grain direction of oak flooring showed the lengthwise grain to have a higher coefficient of friction than the crosswise grain. This was generally true for all combinations of materials tested. The mean coefficient of friction for the lengthwise grain direction was .462, and the mean coefficient of the crosswise grain direction was .445.

The analysis for the oak types did not show a set pattern. Neither red nor white oak was consistently higher in coefficient of friction than the other.

CHAPTER V

COMPARISON OF MATERIALS TESTED IN A DRY CONDITION AND WITH APPLIED MOISTURE

The analysis of variance for each experiment showed highly significant differences in force of friction values for three main effects: wood floor finishes, heel materials, and surface conditions.

The main effect, type of oak flooring, was highly significant in the dry experiment but insignificant in the experiment with applied moisture. The main effect, grain direction of oak flooring, was insignificant for the dry experiment but highly significant for the experiment with applied moisture.

With a few exceptions the same first-, second-, third-, and fourth-order interactions were significant in both experiments. The first-order interaction of the grain direction by heel material was significant in the dry experiment but not with applied moisture. In the second-order interactions, the following were significant in the dry experiment but not with applied moisture.

Wood floor finishes by types of oak flooring and grain directions
Surface conditions by types of oak flooring and heel materials
Surface conditions by grain directions and heel materials

The second-order interaction--types of oak flooring by grain directions and heel materials--was significant with applied moisture but not in the dry experiment.

The significant third- and fourth-order interactions were the same for both experiments.

The major difference between the materials tested in the two experiments was that the coefficients of friction of the materials tested dry were appreciably higher than the coefficients of friction for the materials tested with applied moisture.

I. WOOD FLOOR FINISHES TESTED IN A DRY CONDITION AND WITH APPLIED MOISTURE

Differences in mean coefficients of friction between the finishes tested in the dry and applied moisture experiments are shown in Figure 1. In the dry experiment the range from the lowest mean coefficient of friction to the highest was .468 to .667; with applied moisture, .420 to .491. The mean coefficients of friction for the finishes, with the exception of penetrating seal, in the dry experiment were not only higher than those with applied moisture but also the variability among them was greater.

<u>Penetrating Seal</u>

Penetrating seal ranked lowest among the floor finishes in the dry experiment, but next to highest in the experiment with applied moisture. The mean coefficient of friction of penetrating seal was slightly higher for the experiment with applied moisture than for the dry experiment (Figure 1).

Coefficients of friction were higher in the experiment with applied moisture than in the dry experiment when penetrating seal was tested with the leather and rubber crepe heel materials for all surface conditions, and with the self polishing wax with all heel materials (Figure 2).

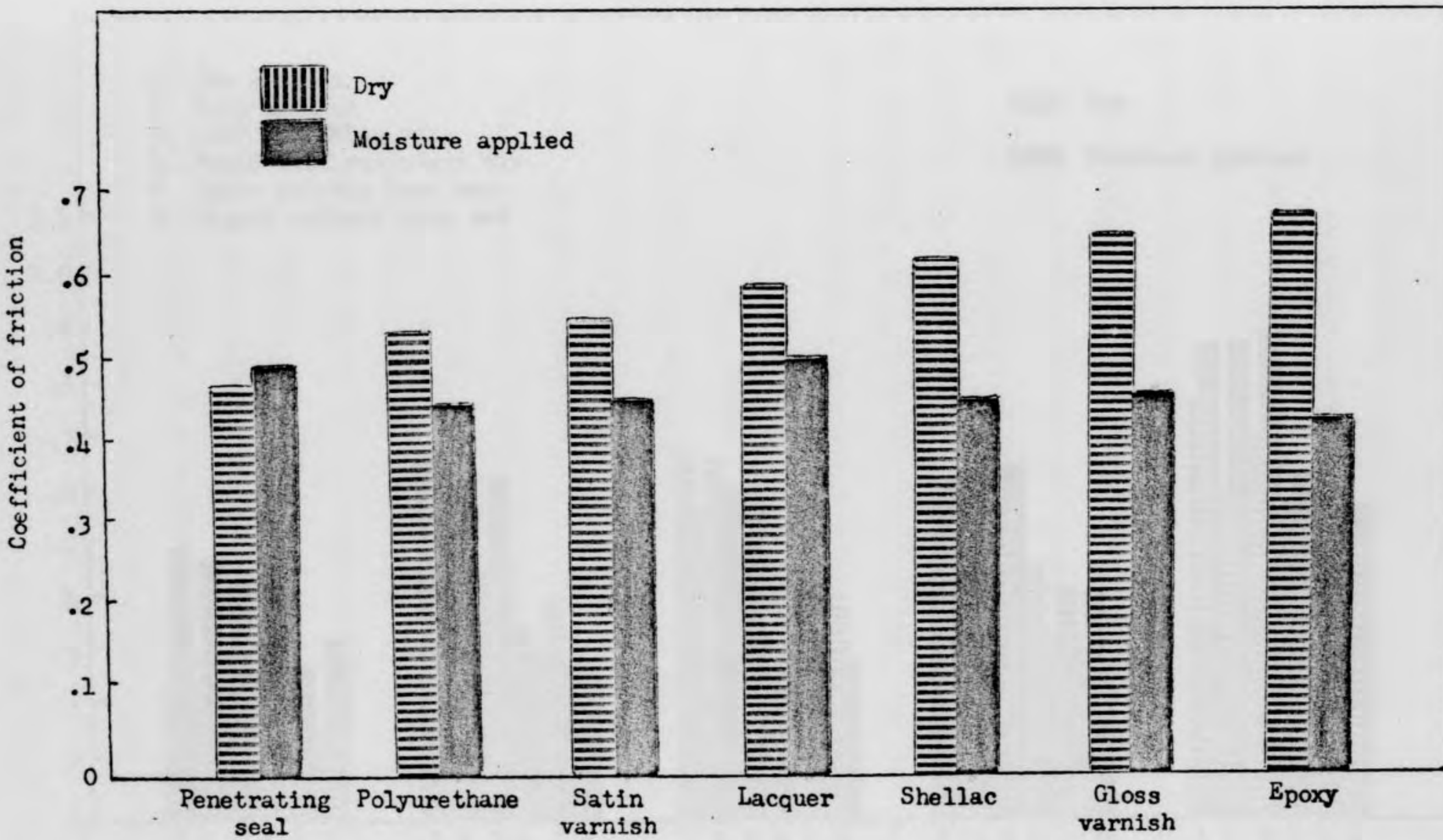

FIGURE 1

MEAN COEFFICIENTS OF KINETIC FRICTION OF WOOD FLOOR FINISHES

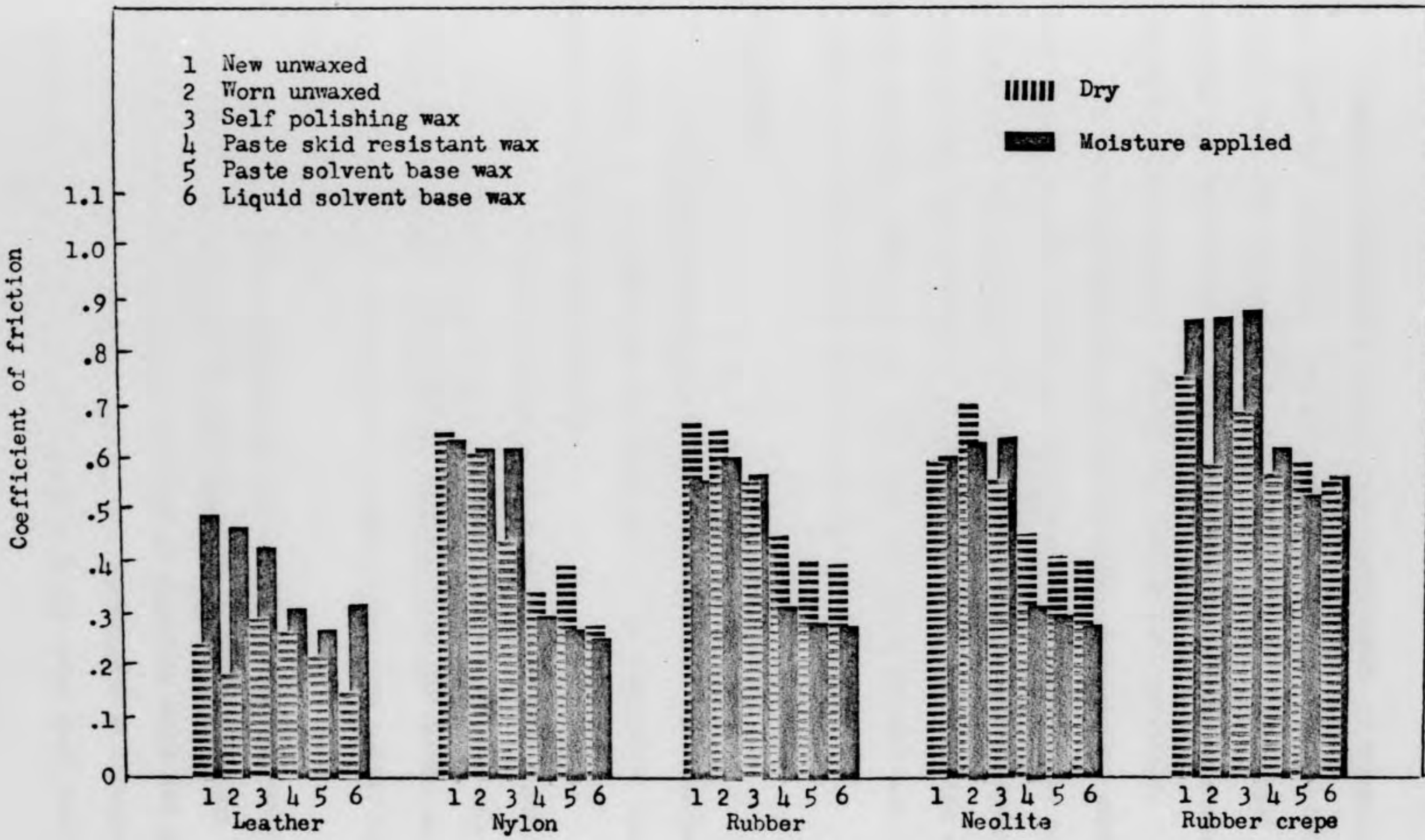

FIGURE 2

MEAN COEFFICIENT OF KINETIC FRICTION OF PENETRATING SEAL IN VARIOUS SURFACE CONDITIONS BY HEEL MATERIALS

Leather consistently showed lower coefficients of friction than the other heel materials. However, an exception was observed for penetrating seal with applied moisture in which case the coefficient of friction for leather with the skid resistant and solvent base waxes was comparable with the nylon, rubber, and Neolite heel materials.

In the experiment with applied moisture, a consistent pattern was shown for the surface conditions with penetrating seal. Three conditions--unwaxed new, unwaxed worn, and self polishing wax--grouped together and showed higher coefficients of friction than the three remaining waxes--skid resistant, paste solvent base wax, and liquid solvent base wax. A similar pattern was not observed in the dry experiment.

Polyurethane

Polyurethane ranked low in both experiments. The mean coefficient of friction of polyurethane was higher in the dry experiment than in the experiment with applied moisture.

The coefficients of friction for polyurethane were higher in the dry experiment with the nylon, rubber and Neolite heel materials for all surface conditions (Figure 3). However, with the leather and rubber crepe heel materials several of the surface conditions tested higher with applied moisture.

The paste skid resistant wax and the self polishing wax with the rubber crepe heel material in both experiments gave the highest coefficient of friction for polyurethane. This was an exception since the paste skid resistant wax generally gave a lower coefficient of friction than the unwaxed conditions for this finish with the other heel materials.

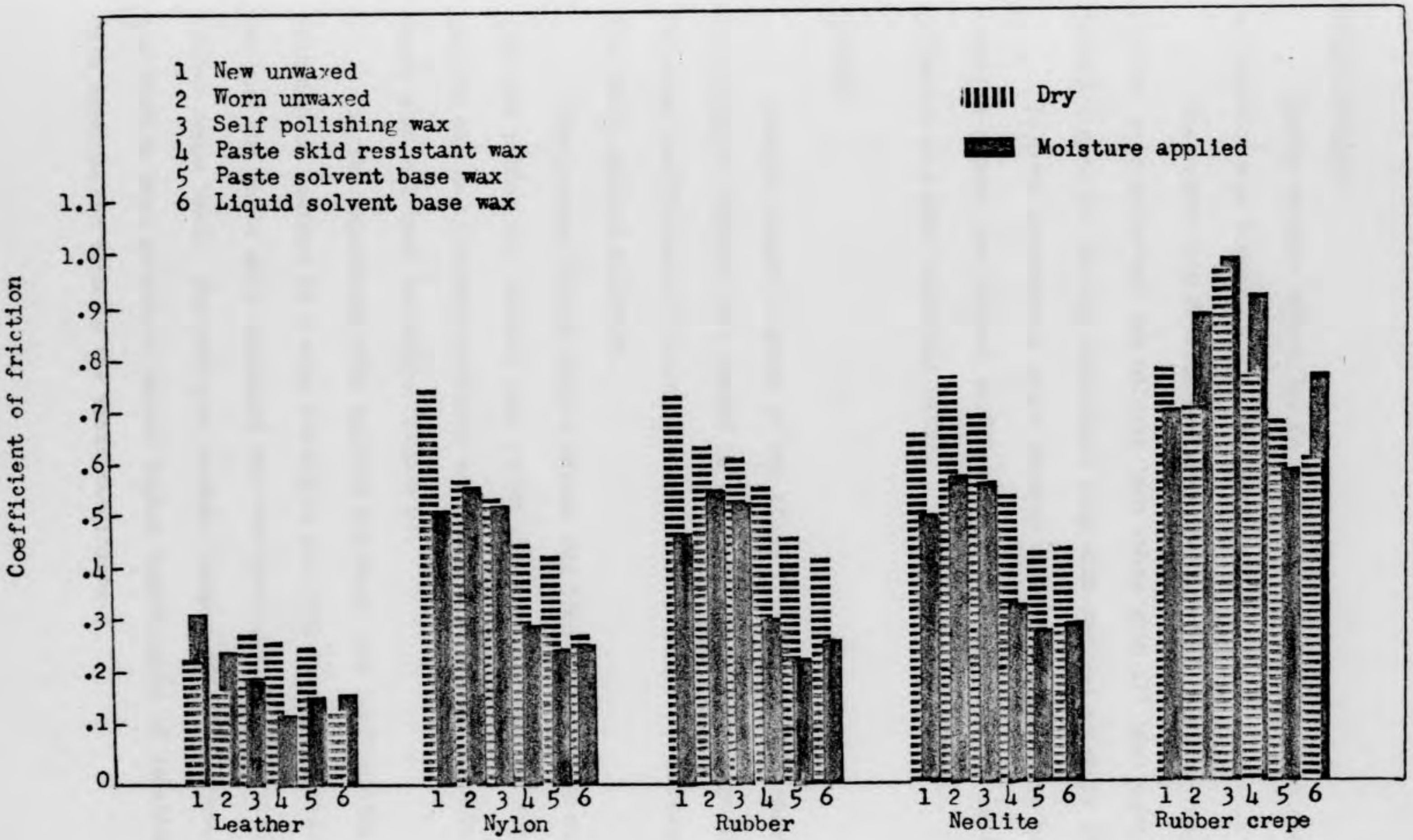

FIGURE 3

MEAN COEFFICIENTS OF KINETIC FRICTION OF POLYURETHANE IN VARIOUS SURFACE CONDITIONS BY HEEL MATERIALS

Satin Varnish

Satin varnish ranked low in both experiments; its mean coefficient of friction was higher in the dry experiment.

The rubber and Neolite heel materials for all surface conditions and the skid resistant and solvent base waxes with all heel materials tested higher in the dry experiment than with applied moisture (Figure 4).

In both experiments satin varnish with the rubber crepe heel material showed the highest coefficient of friction with the self polishing and skid resistant waxes.

Lacquer

Lacquer ranked highest of the floor finishes in the experiment with applied moisture but ranked in the middle in the dry experiment. The mean coefficient of friction was, however, higher for lacquer dry than with applied moisture.

The lacquer finish ranked higher dry than with applied moisture with the rubber and Neolite heel materials under all surface conditions and for the new unwaxed condition and the liquid and paste solvent base waxes with all heel materials (Figure 5).

In the experiment with applied moisture, the coefficients of friction of lacquer in a worn condition and with the self polishing wax and the paste skid resistant wax were particularly high with the rubber crepe heel. New and worn unwaxed lacquer with the nylon, rubber, and Neolite heel materials showed higher coefficients of friction in both experiments than in the waxed conditions.

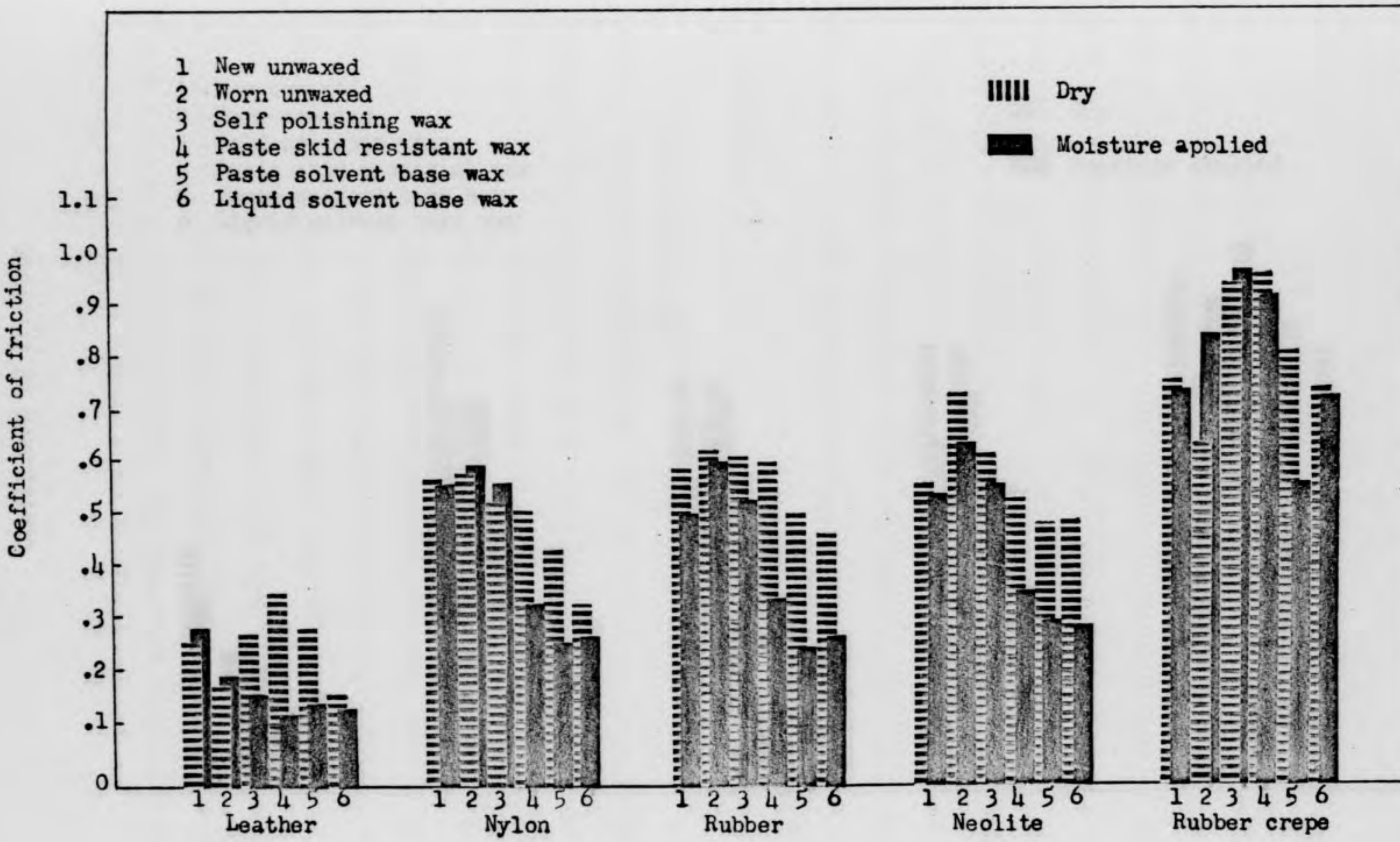

FIGURE 4

MEAN COEFFICIENTS OF KINETIC FRICTION OF SATIN VARNISH IN VARIOUS SURFACE CONDITIONS BY HEEL MATERIALS

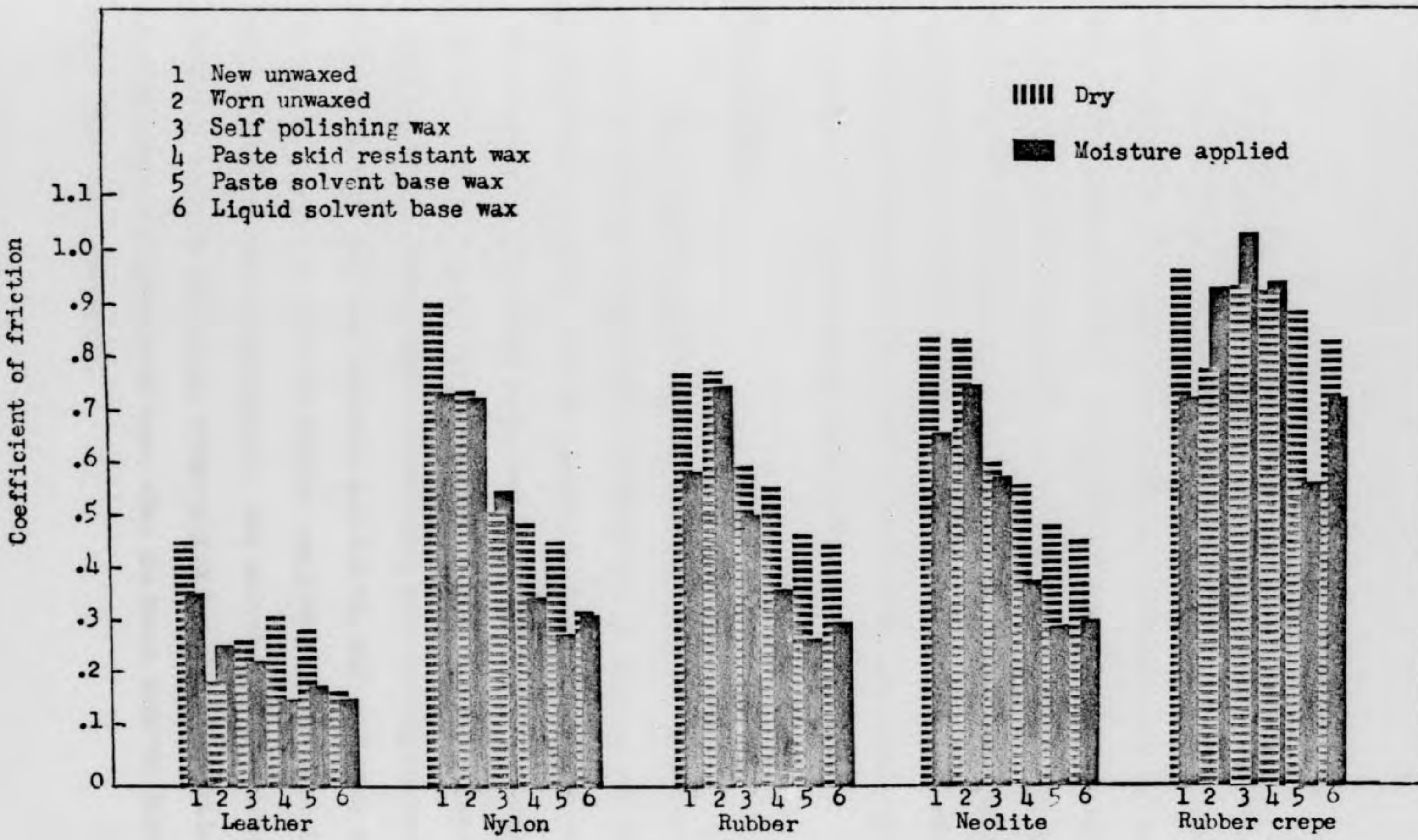

FIGURE 5

MEAN COEFFICIENTS OF KINETIC FRICTION OF LACQUER IN VARIOUS SURFACE CONDITIONS BY HEEL MATERIALS

Shellac

Shellac ranked high in coefficient of friction in the dry experiment, but low in the experiment with applied moisture. With one exception shellac gave higher coefficients of friction when dry for all heel materials and under all conditions (Figure 6). With applied moisture the shellac waxed with the self polishing wax and the skid resistant wax gave the highest coefficient of friction when tested with the rubber crepe heel material. In the dry experiment, shellac in the unwaxed condition with nylon, rubber and Neolite gave higher coefficients of friction than in the waxed conditions.

Gloss Varnish

Gloss varnish ranked high in both experiments. With two exceptions, the dry experiment showed higher coefficients of friction for all heel materials and under all surface conditions (Figure 7). The exceptions were the leather and rubber crepe heel materials tested in combination with the worn condition. In the experiment with applied moisture, gloss varnish with the rubber crepe heel material gave the highest coefficient of friction with the skid resistant wax and the self polishing wax. The new unwaxed condition gave the highest coefficient of friction for each heel material in the dry experiment. The worn unwaxed condition tested relatively high for the nylon, rubber and Neolite heel materials in the dry experiment but relatively lower than the waxes with the leather and rubber crepe heel materials.

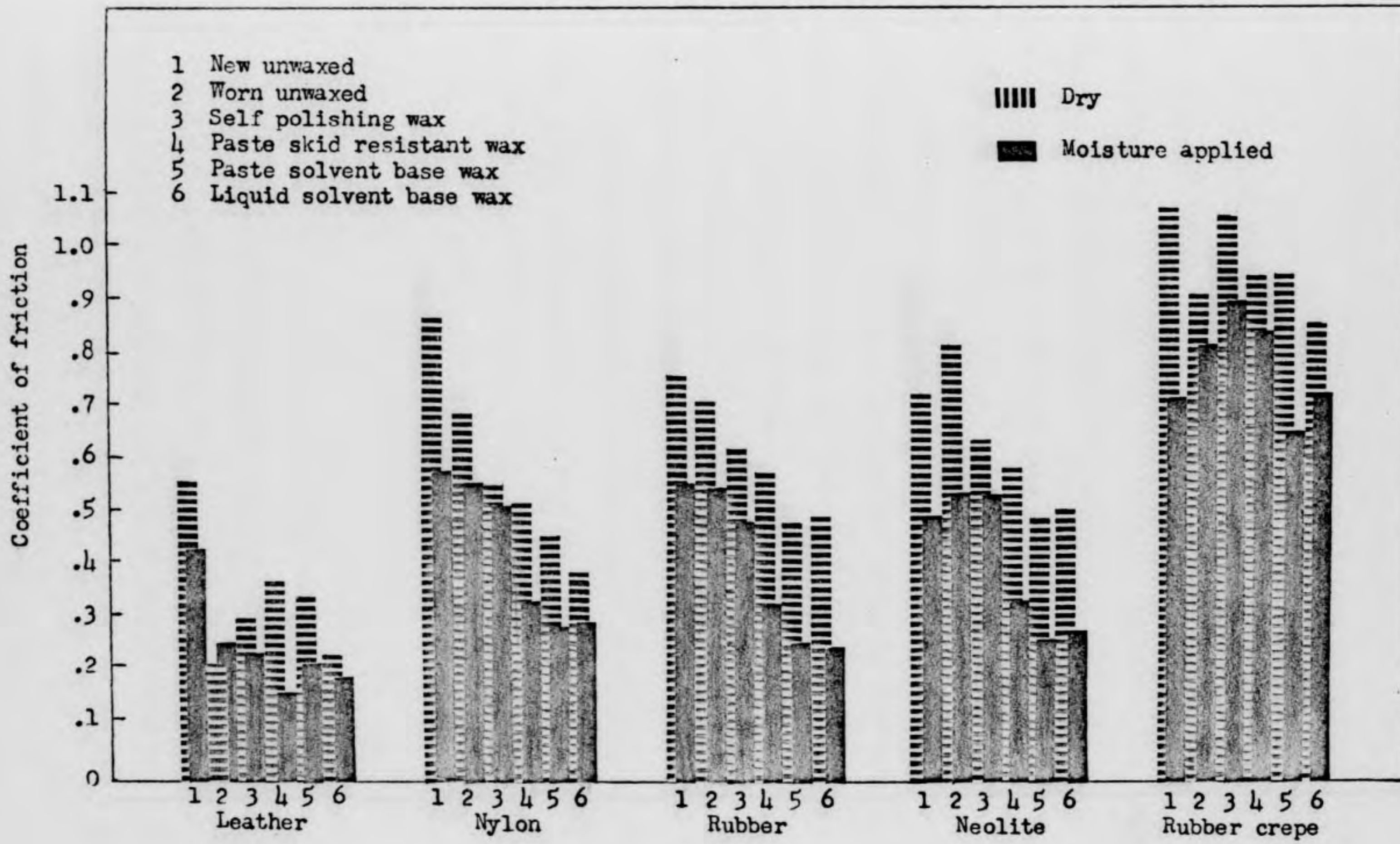

FIGURE 6

MEAN COEFFICIENTS OF KINETIC FRICTION OF SHELLAC IN VARIOUS SURFACE CONDITIONS BY HEEL MATERIALS

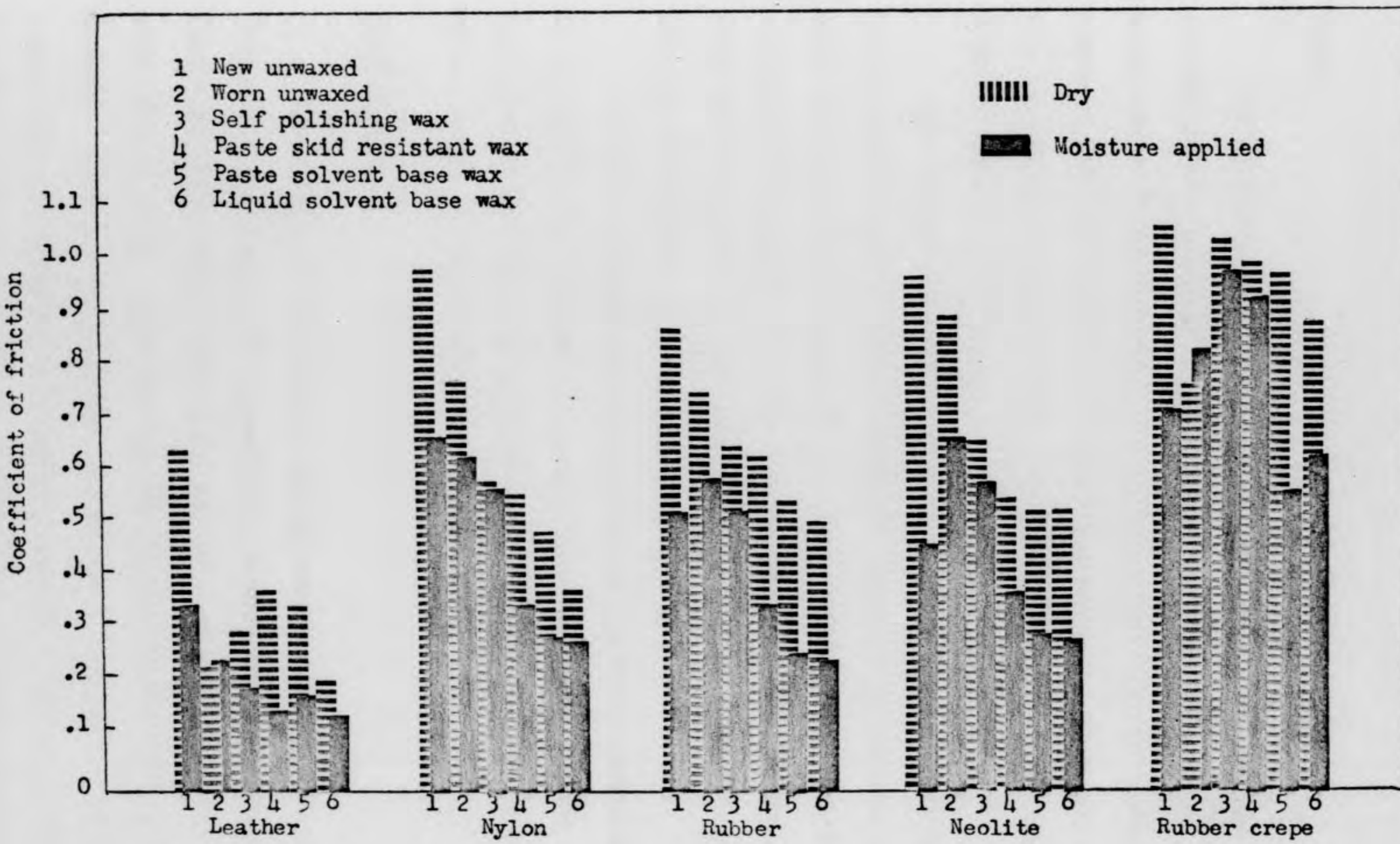

FIGURE 7

MEAN COEFFICIENTS OF KINETIC FRICTION OF GLOSS VARNISH IN VARIOUS SURFACE CONDITIONS BY HEEL MATERIALS

Epoxy

Epoxy was the only finish that tested higher dry than wet with all heel materials and under all surface conditions (Figure 8). The epoxy finish ranked highest of the finishes tested dry but ranked lowest of the finishes tested with applied moisture. There was substantial difference between the mean coefficient of friction of epoxy tested in the two experiments.

The same pattern was noticed for epoxy as for the other finishes in the experiment with applied moisture. Epoxy in the unwaxed conditions and the self polishing wax with four heel materials ranked substantially higher than the other three waxes. However, for the rubber crepe heel material, the self polishing wax and the paste skid resistant wax gave the highest coefficients of friction.

In the dry experiment, the new unwaxed condition tested highest of the surface conditions for all heel materials except Neolite and the worn unwaxed condition tested higher than the waxed conditions with the nylon, rubber and Neolite heel materials.

All Finishes

The ranking of finishes in the dry experiment tested in combination with other factors was consistent. Penetrating seal always ranked lowest and epoxy highest with small variation in the rankings of the other five finishes. This was not true of the finishes with applied moisture. While epoxy more often ranked lowest and lacquer ranked highest in various testing combination, there was great variation in the ranking of all seven floor finishes and no set pattern was observed.

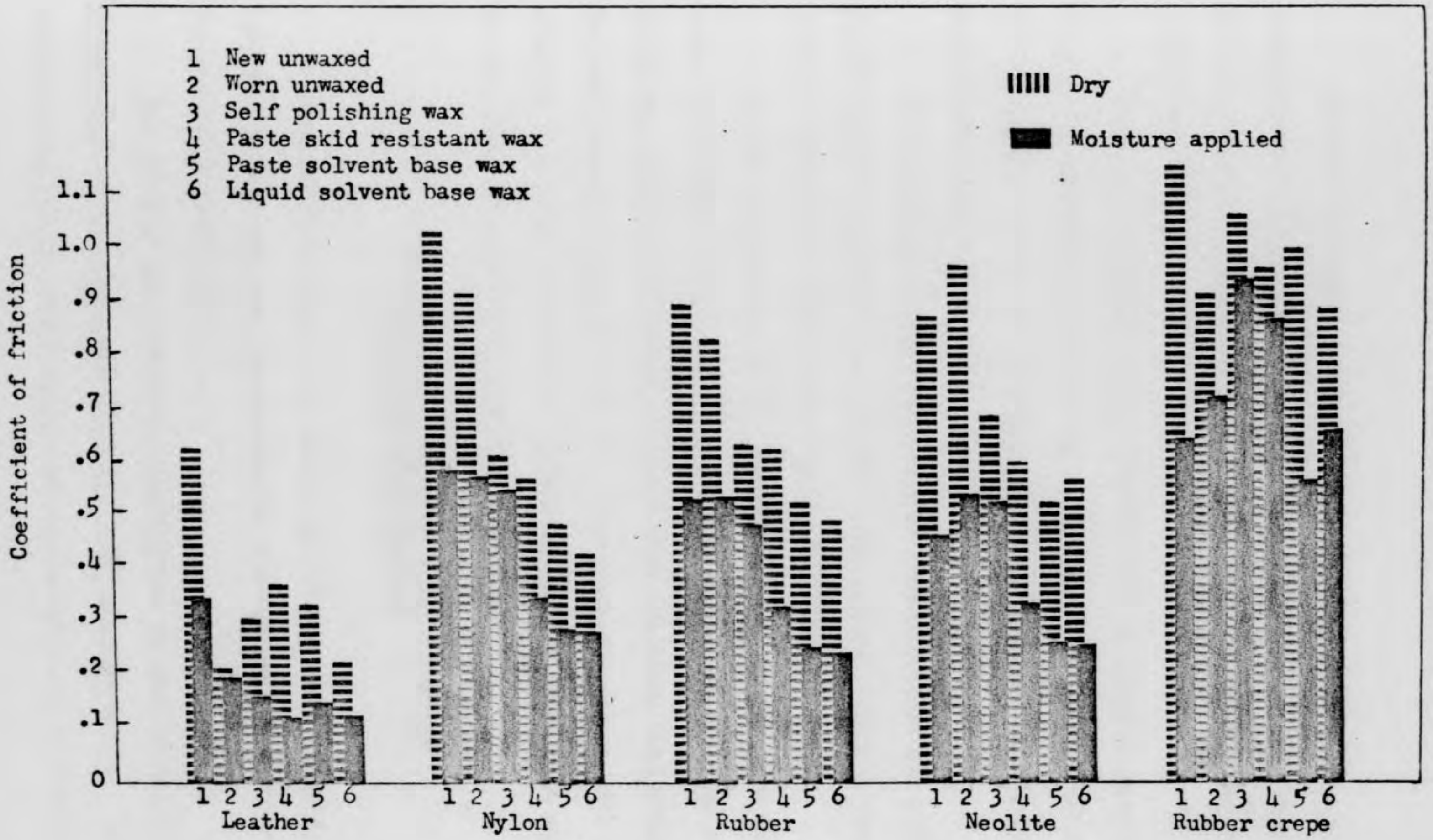

FIGURE 8

MEAN COEFFICIENTS OF KINETIC FRICTION OF EPOXY IN VARIOUS SURFACE CONDITIONS BY HEEL MATERIALS

In both experiments, the analysis showed greater variation in coefficients of friction for the wood floor finishes in combination with the heel materials than for the wood floor finishes under varying surface conditions.

With few exceptions higher coefficients of friction were observed for the dry experiment than for the experiment with applied moisture with the nylon, rubber and Neolite heel materials for all finishes except penetrating seal.

In most cases the penetrating seal, satin varnish and polyurethane showed higher coefficients of friction with applied moisture when tested with the leather and rubber crepe heel materials.

In the dry experiment all finishes in the unwaxed worn condition tested relatively lower than other surface conditions with the leather and rubber crepe heel materials but not with the other heel materials. The worn unwaxed condition also tested consistently higher with applied moisture than when dry with the leather and rubber crepe heel materials for all floor finishes except shellac and epoxy.

II. HEEL MATERIALS TESTED IN A DRY CONDITION AND WITH APPLIED MOISTURE

The analysis showed more similarity in mean coefficients of friction between the two experiments for the heel materials than for the wood floor finishes.

The leather heel material ranked lowest in mean coefficient of friction in both experiments (.220 and .278, respectively). The rubber crepe heel material ranked highest in mean coefficient of friction both dry and with applied moisture (.770 and .856, respectively). The nylon, rubber and Neolite heel materials did not rank in the same order for both experiments, however, in each case their mean coefficients of friction were similar and the three heel materials ranked closely together about halfway between the leather and rubber crepe heel materials. This pattern held true for the heel materials tested in all combinations with other factors. One exception was noticed. This was with the penetrating seal finish with applied moisture where the coefficient of friction of leather with the skid resistant and solvent base waxes was comparable with the nylon, rubber, and Neolite heel materials. There was less variability shown among heel materials for this finish than for the other finishes.

Generally, the coefficients of friction for the heel materials tested dry were slightly higher than those tested with applied moisture.

III. SURFACE CONDITIONS TESTED IN A DRY CONDITION AND WITH APPLIED MOISTURE

Differences between the surface conditions tested dry and with moisture applied are shown in Figure 9. The coefficients of friction for the surface conditions tested dry were higher than the coefficients of friction for the surface conditions tested with applied moisture. For both experiments, the unwaxed surface conditions and the self polishing wax gave higher mean coefficients of friction than the remaining three waxes: skid resistant paste wax and the paste and liquid solvent base waxes. In the dry experiment, the new unwaxed condition gave the highest mean coefficient of friction (.735), and the liquid solvent base wax the lowest mean coefficient of friction (.442), with a gradual

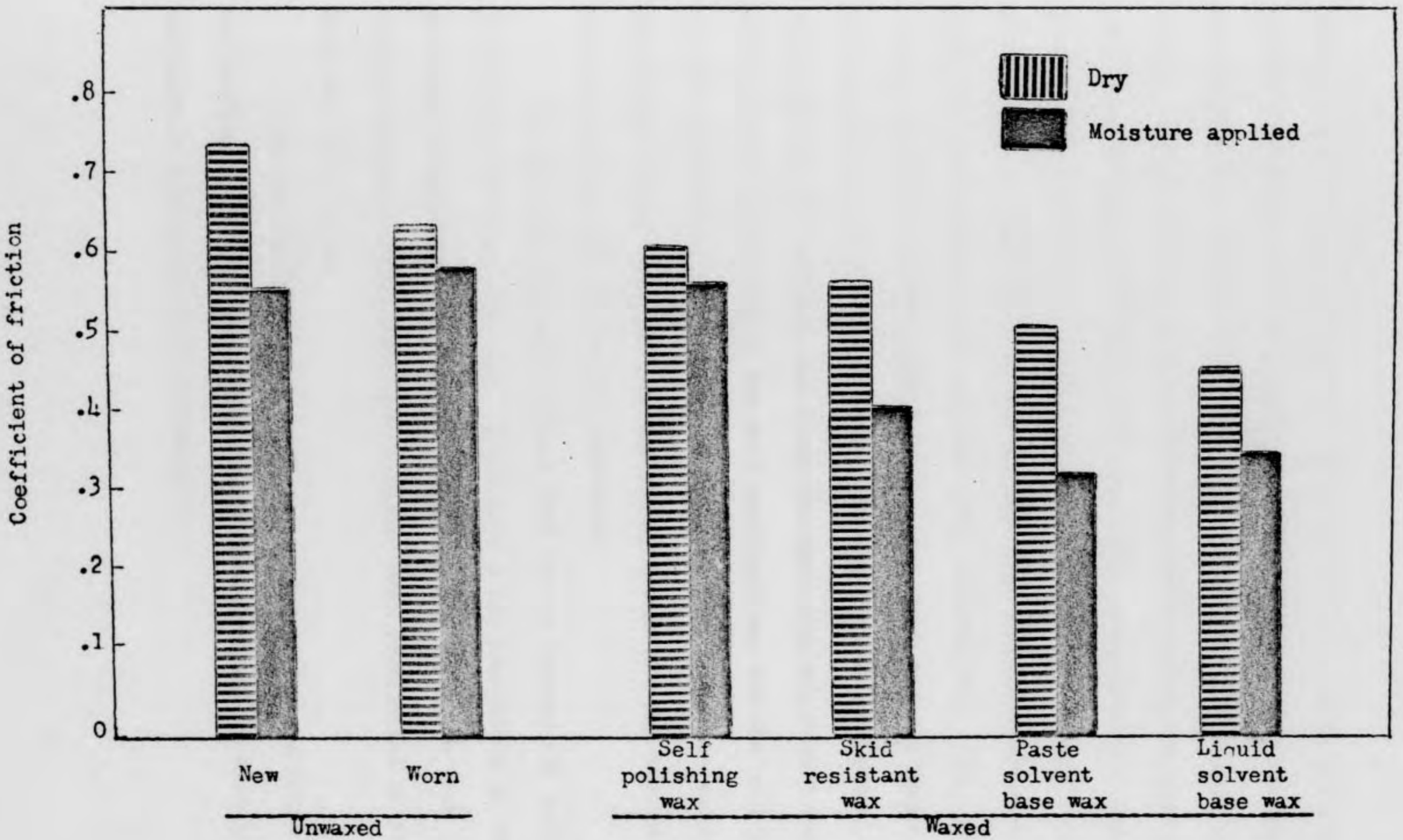

FIGURE 9

MEAN COEFFICIENTS OF KINETIC FRICTION OF SURFACE CONDITIONS ON WOOD FLOOR FINISHES change in mean coefficient of friction from the highest to the lowest surface condition. However, in the experiment with applied moisture, the unwaxed worn condition gave the highest mean coefficient of friction (.579), but both the new unwaxed and the self polishing wax gave similar mean coefficients of friction (.551 and .558, respectively). The paste solvent base wax gave the lowest mean coefficient of friction (.308), while the liquid solvent base wax and the skid resistant wax gave mean coefficients of friction of .330 and .397, respectively. This showed a gap in coefficient of friction between the three highest ranking surface conditions and the three lowest ranking surface conditions. An exception was observed for all floor finishes with the rubber crepe heel material in which case the skid resistant wax and the self polishing wax gave higher coefficients of friction than the other conditions. The liquid solvent base wax was especially low in the dry experiment with the leather and nylon heel materials.

The analysis generally showed that waxing lowered the coefficient of friction of floor finishes. There were a few exceptions in both experiments especially with the self polishing wax which, in both dry and applied moisture experiments gave a higher mean coefficient of friction than the other waxes.

A greater difference in coefficient of friction was noted for the surface conditions in combination with heel materials than in combination with wood floor finishes.

IV. TYPE OF OAK FLOORING TESTED IN A DRY CONDITION AND WITH APPLIED MOISTURE

The white oak in the dry experiment consistently ranked higher in coefficient of friction than the red oak. This was true in all combinations of factors. In several analyses the difference between the oak types was appreciable with the greatest differences occurring in the unpolished conditions, for the nylon heel material, and with the shellac floor finish. However, in the experiment with applied moisture, neither oak type ranked consistently higher; and differences were not appreciable.

The mean coefficients of friction were higher in the dry experiment than with applied moisture.

V. GRAIN DIRECTION TESTED IN A DRY CONDITION AND WITH APPLIED MOISTURE

In the dry experiment, the lengthwise grain more often gave a higher coefficient of friction than the crosswise grain direction. However the differences were not substantial and the analysis was not significant. The analysis for grain direction with applied moisture was significant. The lengthwise grain direction generally showed a higher coefficient of friction than the crosswise grain direction for all combinations of factors tested.

VI. SUMMARY

The coefficients of friction were generally higher for materials in the dry experiment than with applied moisture.

The mean coefficients of friction were higher in the dry experiment for all floor finishes except penetrating seal which was higher with applied moisture. The ranking of the wood floor finishes for the two experiments showed considerable variation; for example, epoxy, the finish ranking highest when dry, ranked lowest with applied moisture; and penetrating seal, the finish ranking lowest when dry, ranked next to highest with applied moisture. In the dry experiment, the finishes ranked more consistently for all factor combinations than with applied moisture.

In both experiments the heel materials ranked in a consistent order. Leather had the lowest coefficient of friction; and rubber crepe, the highest. Nylon, rubber, and Neolite heel materials generally gave higher coefficients of friction dry than with applied moisture. However, with the rubber crepe and leather heel materials, the coefficient of friction was frequently higher with applied moisture.

Waxing lowered the coefficients of friction of the wood floor finishes in both experiments. In several cases, the self polishing wax was an exception, testing higher than one or both unwaxed conditions. The self polishing wax gave the highest coefficient of friction of the four waxes. The paste and liquid solvent base waxes tested lowest in both experiments. The worn condition, in most cases, tested higher dry than with applied moisture in combination with the leather and rubber crepe heel material but not with the nylon, rubber, and Neolite heel materials.

The white oak consistently ranked higher in coefficient of friction than the red oak in the dry experiment. With applied moisture, no pattern was observed.

The lengthwise grain direction more often gave a higher coefficient of friction than the crosswise grain direction for both experiments, but the differences were not appreciable.

CHAPTER VI

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

I. SUMMARY

This investigation of the "Skid Resistance of Wood Floor Finishes Under Varying Surface Conditions" was a phase of a larger project entitled, "The Testing of Smooth Floor Surfaces and Finishes from the Standpoint of Safety," which contributes to Southern Regional Housing Research Project S-54.

The purposes of the investigation were: (1) to determine the coefficients of friction of various combinations of wood floor finishes and heel materials: (a) in a dry condition, and (b) with applied moisture; (2) to determine the effect of wood floor waxes on the frictional values of wood floor finish and heel material combinations: (a) in a dry condition, and (b) with applied moisture; (3) to compare the coefficients of friction of new, worn and waxed wood floor finishes tested in combination with heel materials: (a) in a dry condition, and (b) with applied moisture.

The Bowen Friction Tester was used to measure kinetic friction of wood floor finishes under varying surface conditions. The machine consists of three major parts: (1) a movable circular table which rotates under a weight platform-heel holder (2) an electric motor, and (3) a mechanical recorder.

Red and white strip oak flooring in the standard pattern was used for the construction of the twenty-eight test panels. The panels were cut into trapezoidal shapes to fit the circular surface of the friction tester. The white oak panels were mounted on one side of the ring, alternating grain lengthwise and crosswise. The red oak panels were placed in a like manner on the other half of the ring.

Seven wood floor finishes were selected for testing: varnish (gloss and satin), shellac, lacquer, penetrating seal, polyurethane, and epoxy. Each finish was applied to two white oak panels, one in each grain direction, and to two red oak panels, one in each grain direction.

Five heel materials were tested: leather, rubber, nylon, Neolite, and rubber crepe. For each type of material, two samples were obtained from different manufacturers, giving a total of ten heel materials to be tested. Each heel material test specimen was one-inch square in size.

The wood floor finishes were tested unwaxed (new and worn) and waxed with each of four waxes: a self polishing wax, a liquid solvent base wax, a paste solvent base wax, and a paste skid resistant wax.

The combinations of materials were tested both dry and with applied moisture giving a total of 120 tests, 6,720 measurements. For each test the circular table was revolved twice under the weighted heel platform. This provided for two determinations of each combination of factors.

Each of the five types of heel materials was tested in a different track on the testing surface. This gave a comparable testing surface for each heel material.

The wood floor finishes were tested first in a new condition. They were then worn by an accelerated method using No. 400-A carborundum paper attached to the weight platform of the testing machine, and tested in the worn condition. The wood floor finishes were tested in each of four waxed conditions. Application of the self polishing wax and the liquid solvent base wax was done in accordance with an ASTM method for hand application. The paste solvent base wax and the paste skid resistant wax were weighed prior to their application and the amount used on each panel was equal in weight to the amount of the liquid waxes used. The liquid solvent base wax and both paste waxes were buffed. The self polishing wax was not buffed. After testing of each wax, it was removed with a mineral spirit.

The data were treated to an analysis of variance. Two separate experiments were analyzed corresponding to the wet and dry conditions of the tested materials. Each experiment was a factorial design with split plot features.

Results showed that the main effects, wood floor finishes, heel materials and surface conditions, were highly significant in both experiments. In the dry experiment, the main effect , type of oak flooring, was highly significant; and in the experiment with applied moisture, the main effect, grain direction, was highly significant.

The coefficients of friction were generally higher for materials in the dry experiment than in the experiment with applied moisture.

In the dry experiment, the epoxy finish gave the highest coefficient of friction; and the penetrating seal, the lowest. The seven floor finishes generally showed the same ranking for all factor combinations.

In the experiment with applied moisture, the epoxy finish gave the lowest coefficient of friction; and the penetrating seal and lacquer ranked highest. In this experiment there was variation in the ranking of the seven floor finishes over all factor combinations. The mean coefficients of friction were higher in the dry experiment for all floor finishes except penetrating seal which was higher with applied moisture. There was greater range in the coefficients of friction of the wood floor finishes tested dry than with applied moisture.

In both experiments the leather heel material gave the lowest coefficient of friction, and the rubber crepe heel material gave the highest coefficient of friction. The coefficients of friction for nylon, rubber, and Neolite were generally similar and were about halfway between the leather and rubber crepe heel materials. This pattern was true for the heel materials tested with various combinations of factors. Much greater variation was noted in the coefficients of friction of heel materials than for any of the other factors. The nylon, rubber, and Neolite heel materials generally gave higher coefficients of friction dry than with applied moisture. However, with the rubber crepe and leather heel materials the coefficients of friction were frequently higher with applied moisture.

In general, waxing the floor finishes lowered the coefficients of friction below what they were in the unwaxed condition. Neither the new or worn unwaxed condition ranked higher consistently. The self polishing wax consistently gave higher coefficients of friction than the other waxes and occasionally tested higher than one or both unwaxed conditions.

The paste and liquid solvent base waxes consistently ranked lowest in coefficient of friction. In both experiments, the self polishing wax and the skid resistant wax tested relatively high with the rubber crepe heel material.

The analysis showed the white oak to give consistently higher coefficients of friction than the red oak in the dry experiment. With applied moisture no pattern was shown. The lengthwise grain direction generally gave slightly higher coefficients of friction than the crosswise grain direction for both experiments. The differences, however, were not appreciable.

II. CONCLUSIONS

The following conclusions are drawn from this investigation.

1. The skid resistance of wood floor finishes, with the exception of penetrating seal, was generally lowered by moisture. The skid resistance of penetrating seal was improved with moisture when tested with the leather and rubber crepe heel materials.

2. The wood floor finishes did not give the same rank order when tested with moisture applied as when dry. Epoxy gave the highest coefficient of friction when dry, while penetrating seal gave the lowest. However, with moisture applied, epoxy gave the lowest and lacquer the highest coefficient of friction.

3. The heel materials showed great variation in coefficients of friction. The leather heel material consistently gave the lowest coefficient of friction and rubber crepe the highest. There was little difference among rubber, nylon, and Neolite.

4. Waxing wood floor finishes generally lowered the skid resistance.

5. The self polishing wax gave the highest coefficient of friction of the waxes tested; the liquid and paste solvent base waxes, the lowest. The skid resistant wax did not prove to be the most skid resistant of the waxes tested.

6. The white oak was generally more skid resistant than the red oak.

7. Grain direction did not make an appreciable difference in the skid resistance of wood floor finishes.

III. RECOMMENDATIONS

The following recommendations are made with respect to the results of this investigation:

1. Due to the great variation in the coefficient of friction of shoe heel materials, such information should be made available to the consumer as a criterion for the selection of these materials.

2. In slips and falls on floors the blame is frequently attributed to the flooring material and its condition. Information gained in this study indicates that heel materials may also play a major role in slips and falls. Therefore a comprehensive study of heel materials as a contributing factor in accidents is recommended.

3. Persons should be warned to stay off wet finished wood floors due to the lowering of their skid resistance in this condition.

4. Information on wearability of wood floor finishes would enable the establishment of a correlation between skid resistance and wearing qualities.

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APPENDIX

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DESCRIPTION OF WOOD FLOOR FINISHES

Epoxy - Expxies are a class of resins derived from the interaction of epichlorohydrin and bis-phenol. These resins are thermosetting when cured in the presence of catalysts and yield hard, tough, adherent films with good abrasion, water and alkali resistance. Combined with vegetable oil fatty acids, they yield esters which are useful in the manufacture of highly resistant industrial finishes.

Floor Seal - A floor seal is chemically identified as a linseed oil-modified polyol, maleate, phthalate polyester reduced in aliphatic mineral spirits solvent. It is used as a penetrat for wood substrates to increase abrasion resistance of the wood.

Lacquer - The term Lacquer is restricted to coatings of which the characteristic ingredient is a solution of nitrocellulose or "pyroxylin" in a combination of ester, ketone and alcohol solvents. Nitrocellulose is the nitric acid ester of cellulose produced by subjecting the short fibers of cotton to the action of mixed nitric acid and sulphuric acid. Drying of a lacquer film is accomplished through the evaporation of the solvent.

Polyurethane - When an isocyanate reacts with a hydroxy compound, an addition reaction takes place giving a urethane. If polyfunctional compounds are used, useful polymers, polyurethanes are formed and some of these find application in the surface coating field. Polyurethane finishes contain polyisocyanates and polyhydroxy compounds and, in some cases, amines which serve as catalysts and cross linking agents.

Shellac - Shellac is an exudation from the Coccus Lacca on the smaller branches of certain members of the fig family in India and neighboring countries. In this form, it is designated as "stick lac" and after boiling to extract the red "lac dye," it is known as "seed lac". This is melted, strained and made into thin films which, broken into small flakes, become "shellac". Shellac varnishes are made by dissolving the shellac in an alcohol solvent.

Varnish - Varnish is a solution which when spread upon a surface in a thin film dries by the evaporation of its volatile constituents, by the oxidation of chemical reaction of other constituents, or partly by evaporation and partly by oxidation and chemical reaction to a continuous protective coating which may be either highly lustrous or practically devoid of luster. "Alkyds," which are members of the varnish family, are reaction products of polyhydric alcohols and polybasic acids to form polyesters. These polyesters combined with drying oils, such as linseed oil, produce a fluid material which when spread in a thin film will oxidize to the desired protective membrane. A typical alkyd is "Linseed Glycerol Phthalate".

F. J. Martinek of the Sherwin-Williams Company, in letters dated March 12 and March 31, 1965. Permission to quote secured.